

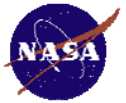
# **Safety of Lithium-ion Cells at Different States of Charge**

**Judith Jeevarajan, Ph.D.  
NASA-JSC**

**and**

**Joe Oriekwu  
Jacobs Technology/NASA-JSC**





# Introduction

- NASA-JSC's state-of-the-art cell surveillance program
- Tested Cells (79 of each type)

|                                   |              |
|-----------------------------------|--------------|
| Manufacturer                      | LG           |
| Nominal capacity (Ah)             | 3            |
| Charge voltage (V)                | 4.2          |
| Discharge termination voltage (V) | 3.0          |
| Chemistry                         | Lithium-ion  |
| Type                              | pouch        |
| Height (mm)                       | 70.1         |
| Width (mm)                        | 68.6         |
| Thickness (mm)                    | 5.03         |
| Mass (g)                          | 52.5 +/- 2.0 |

**LG Li-ion Polymer/ Pouch**



**LG Li-ion 18650**



## Cell Info

Dimensions: 18 mm diam; 65 mm height

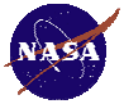
Voltage:  $4.35 \pm 1\%$  - 3.0 V

Capacity (C): 3.0 Ah

Mass:  $48.5 \pm 2.0$  g

Cells Tabbed: No

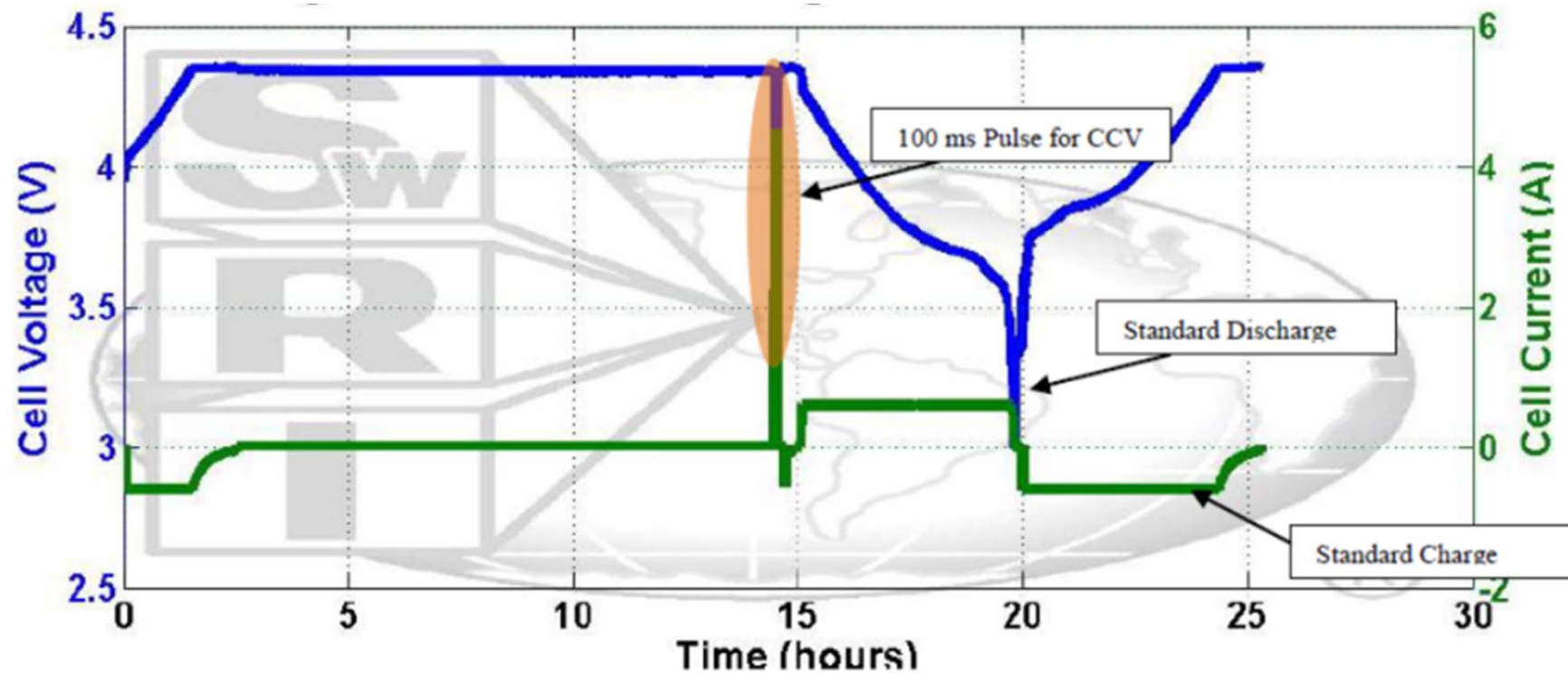




# Initial Charge/Discharge Characteristics

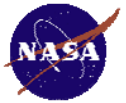
- All cells were cycled using a C/5 rate of charge and discharge;
- EOCV for Li-ion pouch is 4.2 V and 4.35 V for Li-ion 18650 cells

LG 18650 Li-ion Cell Charge/Discharge Plot

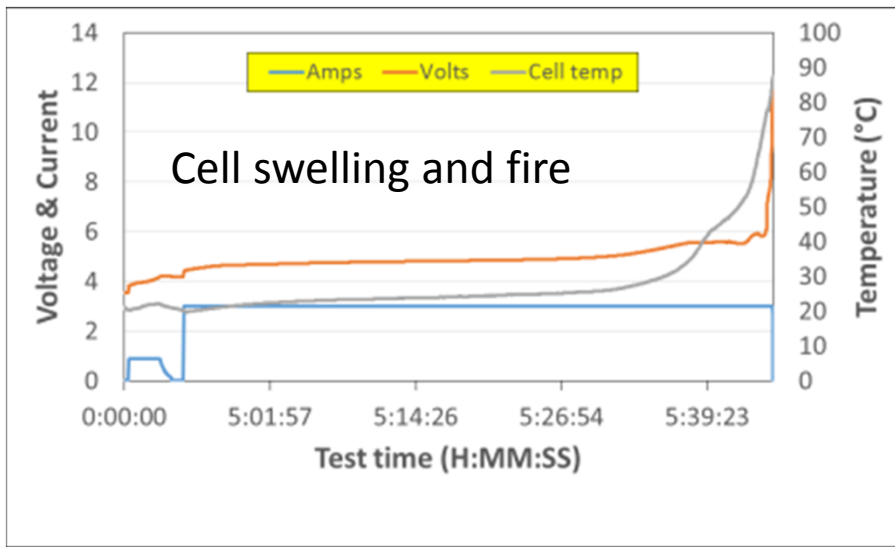
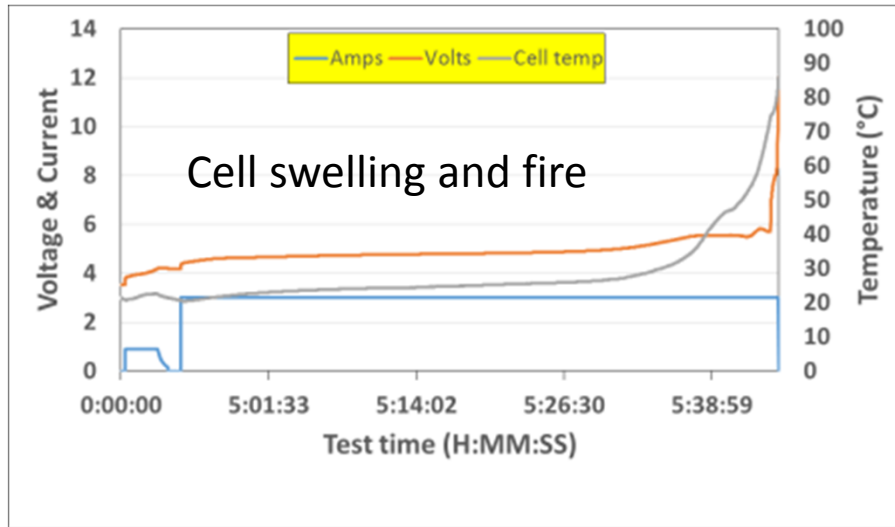


# Overcharge Test (3A Charge Current)

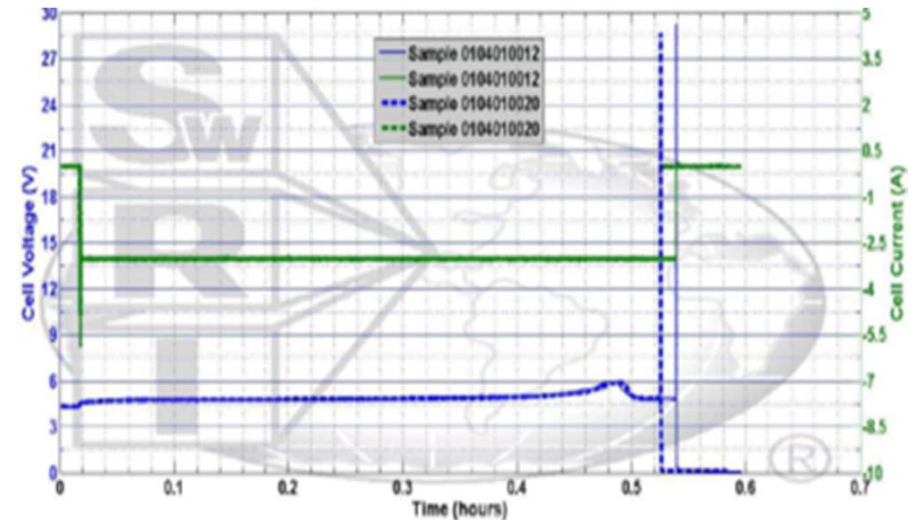
12 V limit; maximum overcharge time - 6 hours



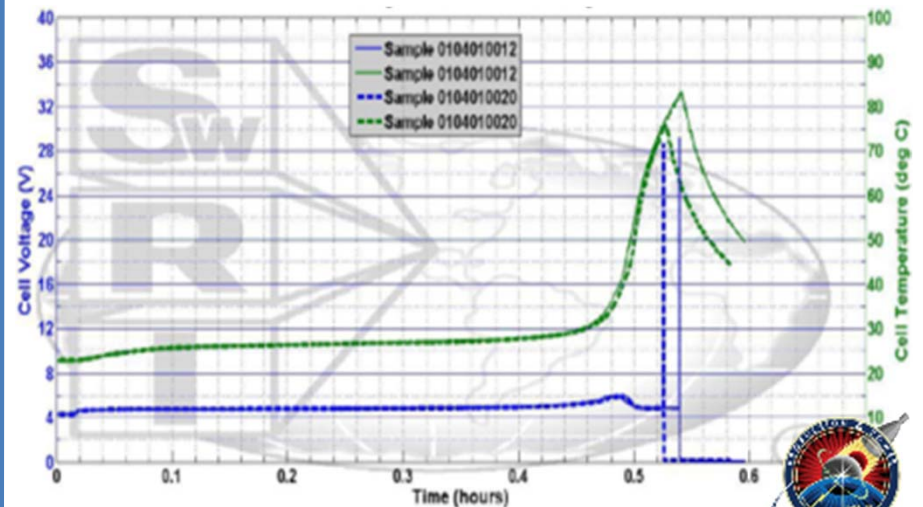
Li-ion Pouch



Li-ion 18650

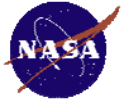


CID Activation

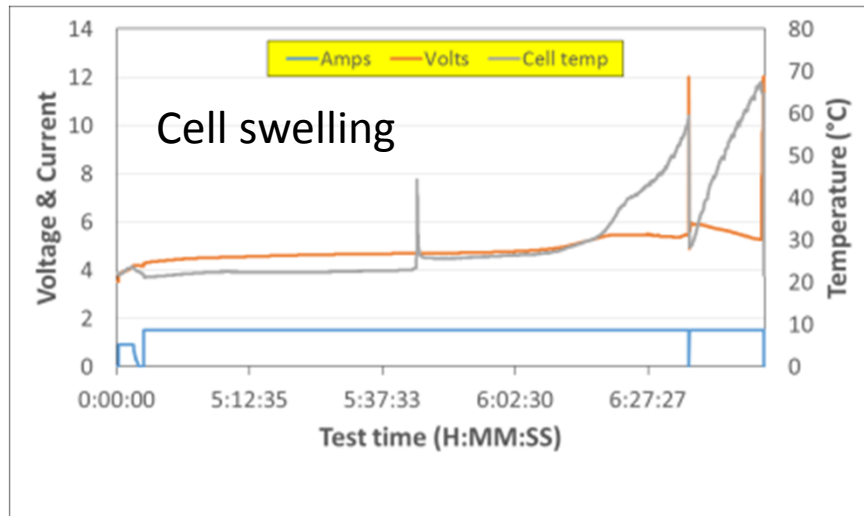


# Overcharge Test (1.5A Charge current)

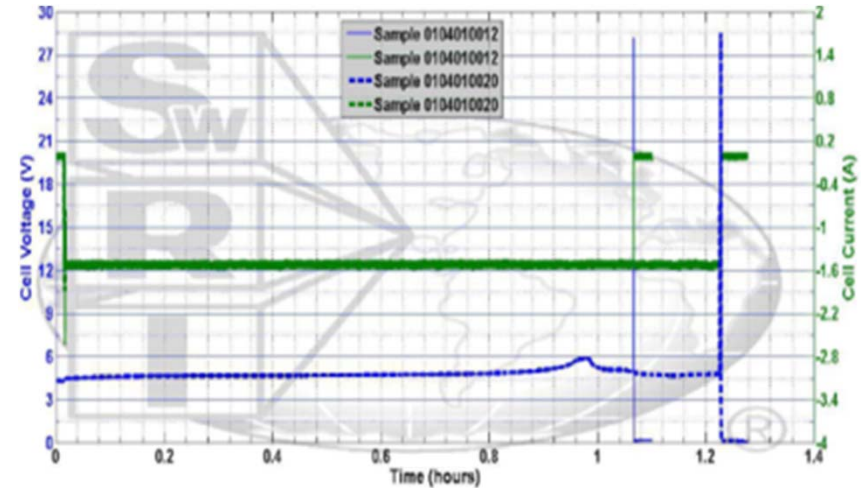
12 V limit; maximum overcharge time - 6 hours



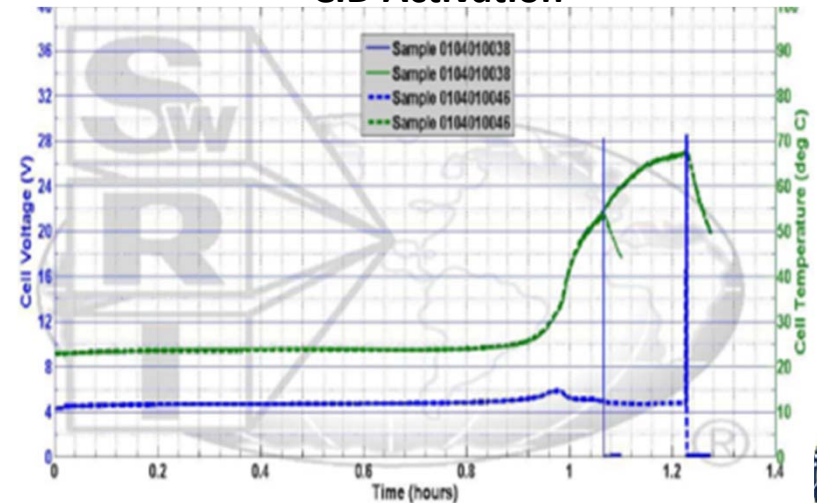
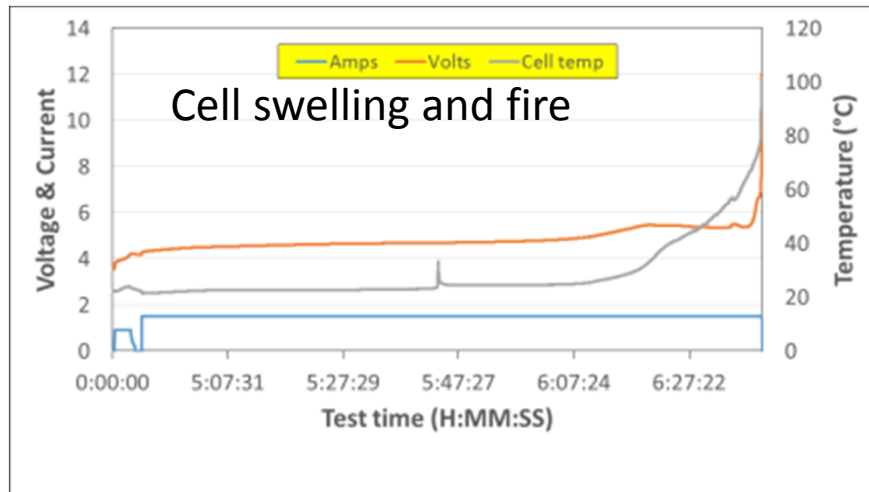
## Li-ion Pouch



## Li-ion 18650

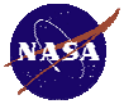


## CID Activation

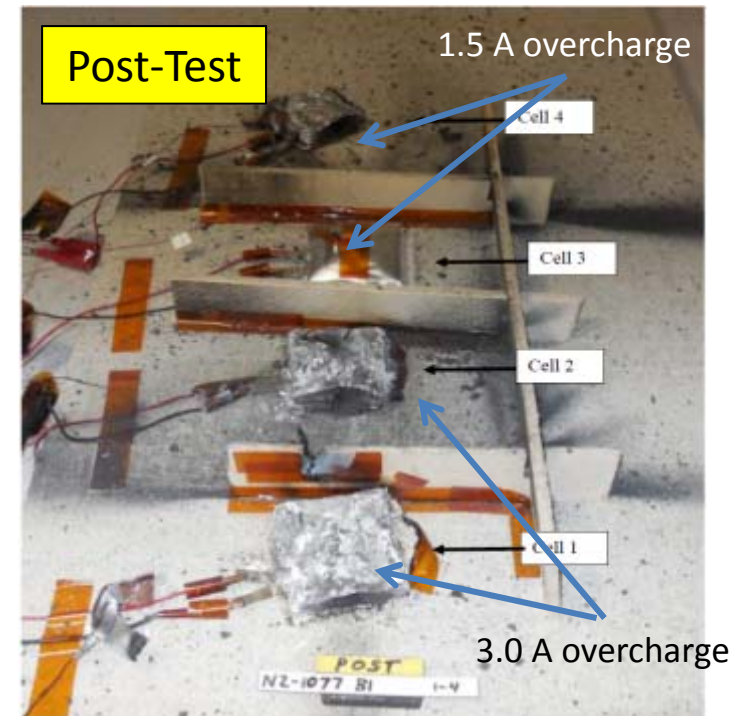
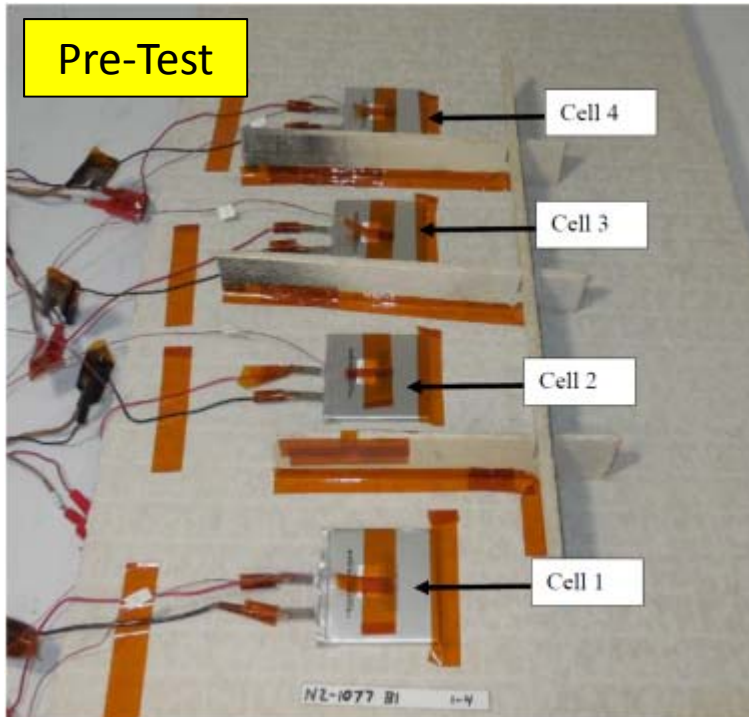




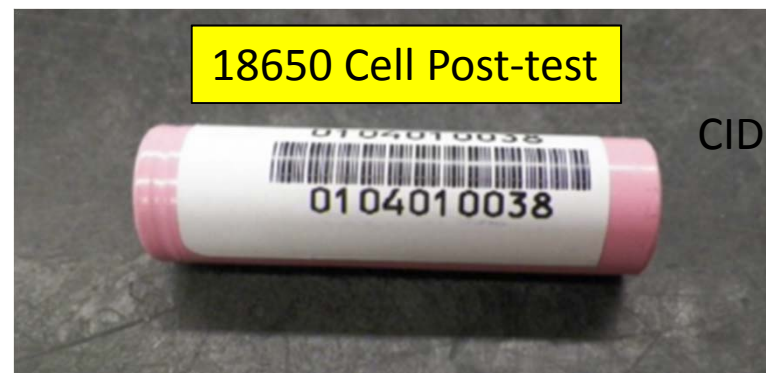
# Overcharge Test Photos



Li-ion Pouch



Li-ion 18650



CID activated

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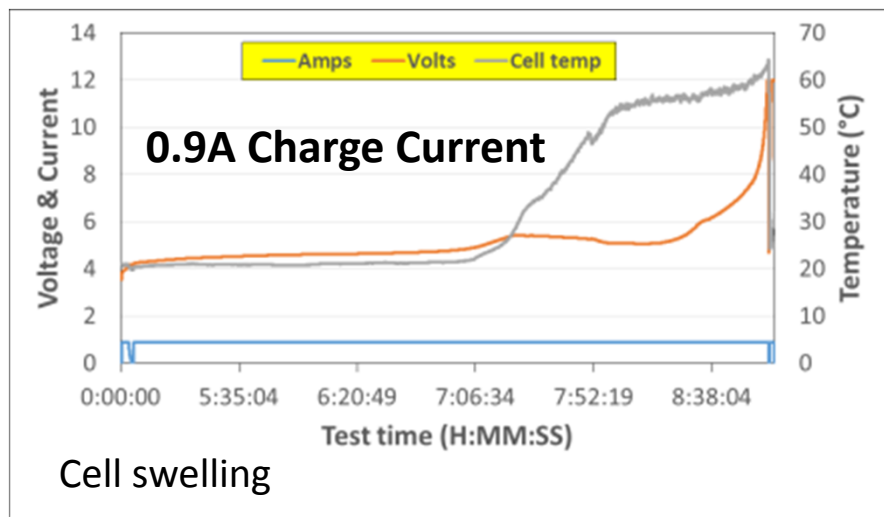


# Overcharge Test

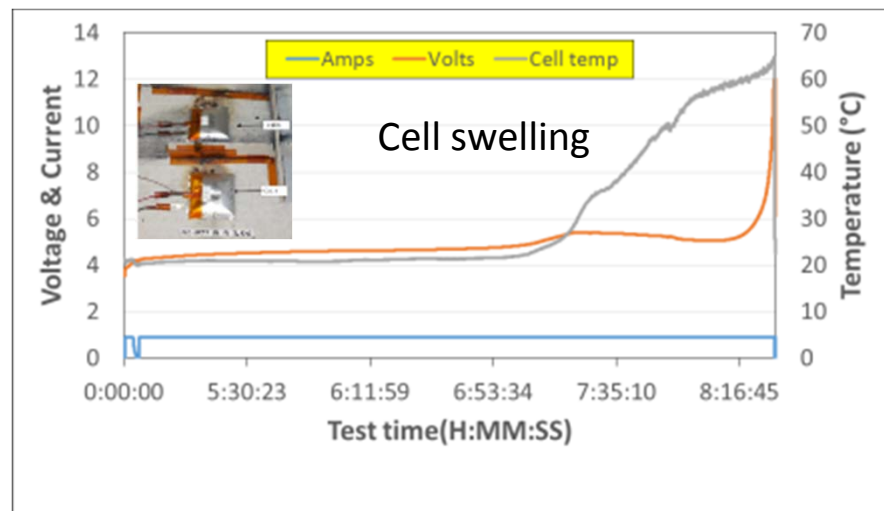
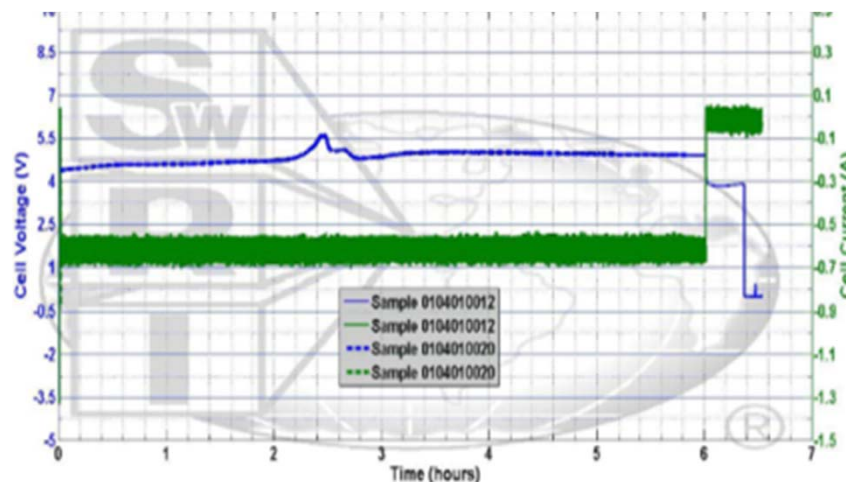
12 V limit; maximum overcharge time - 6 hours



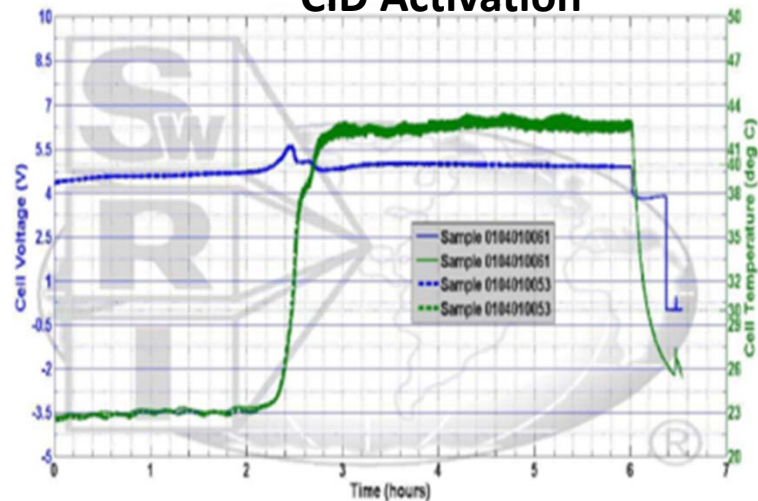
Li-ion Pouch



Li-ion 18650



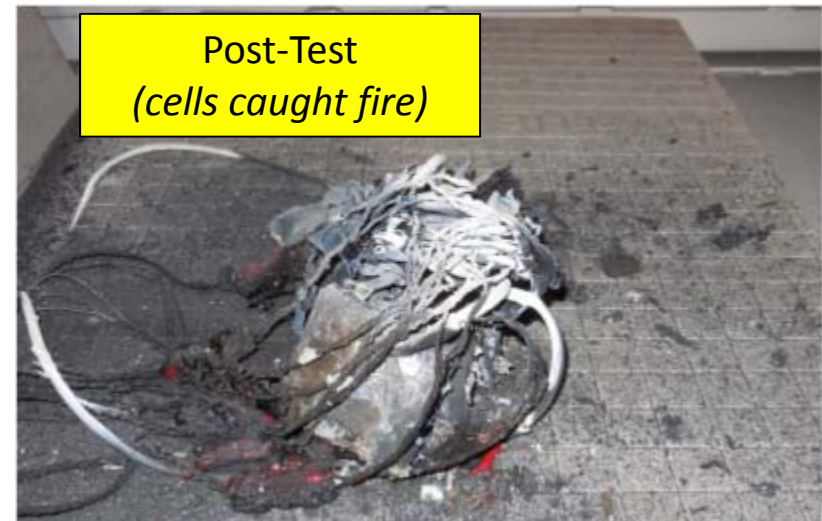
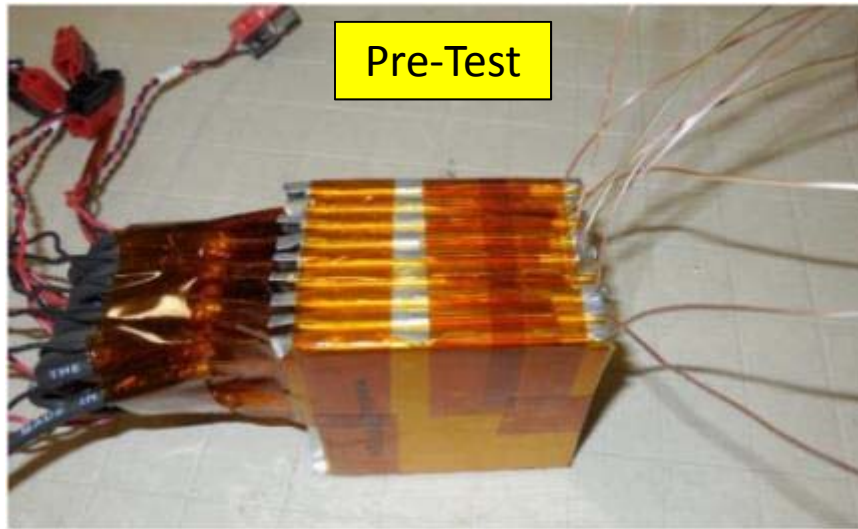
CID Activation



# 9S String Overcharge

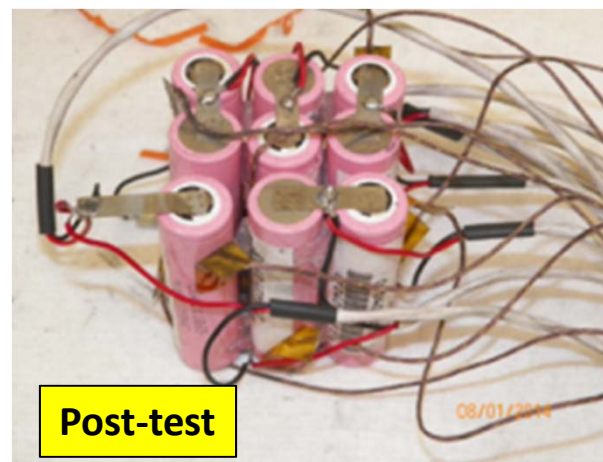
## Li-ion Pouch

(0.9 A Charge Current to 64 V limit); 6 hours max



(3 A Charge Current to 64 V limit); 6 hours max

## Li-ion 18650



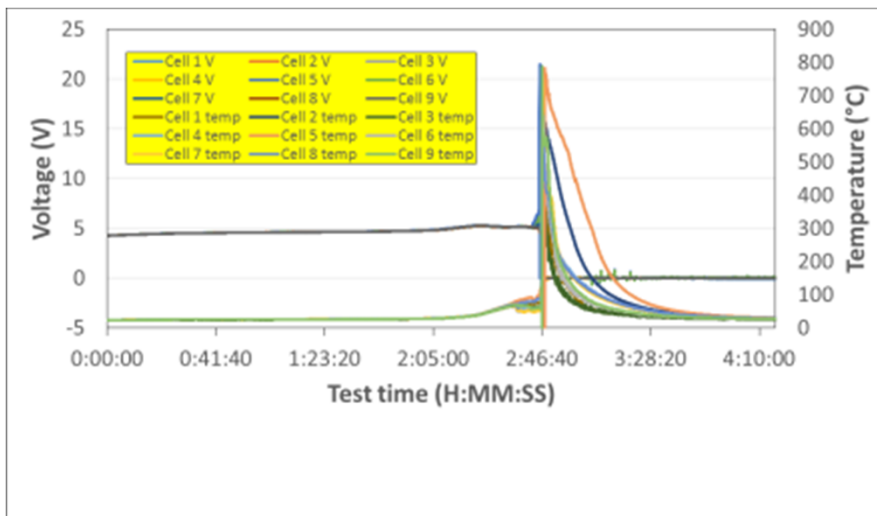
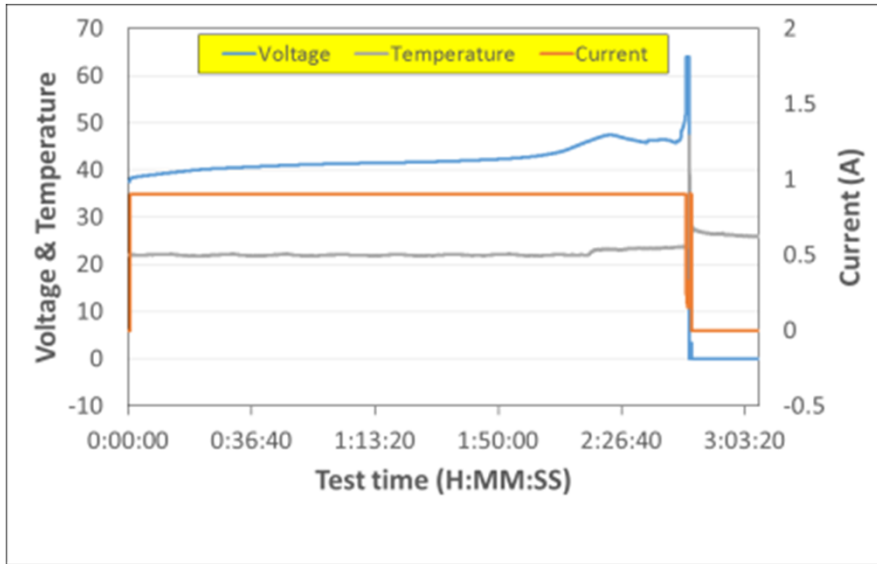
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# 9S String Overcharge Test

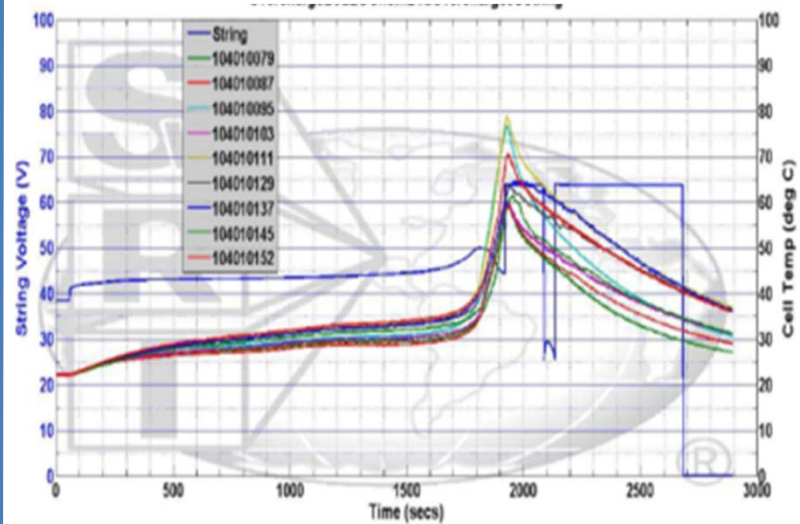
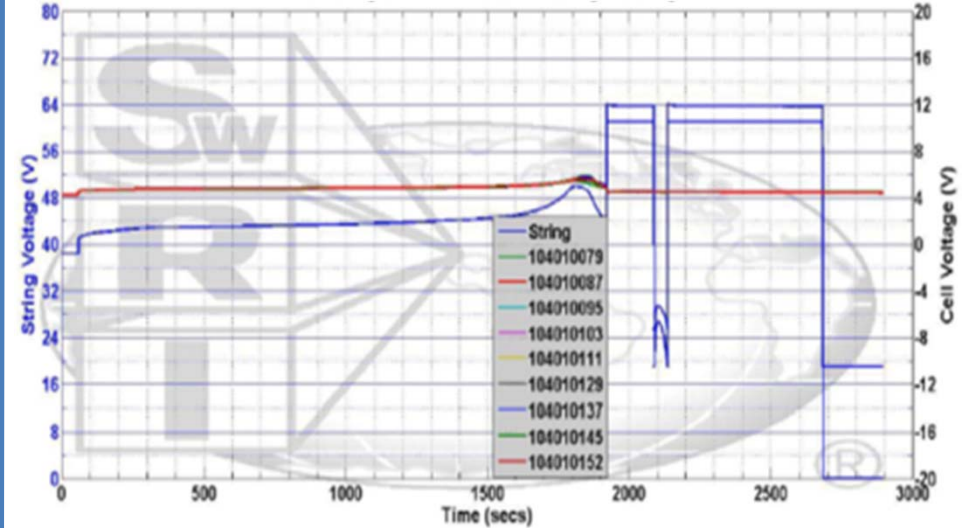
Li-ion Pouch

(0.9 A Charge Current to 64 V limit); 6 hours max



Li-ion 18650

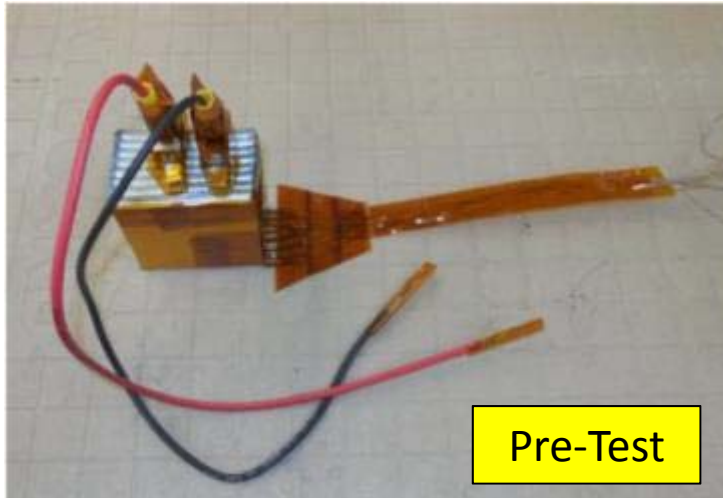
(3 A Charge Current to 64 V limit); 6 hours max



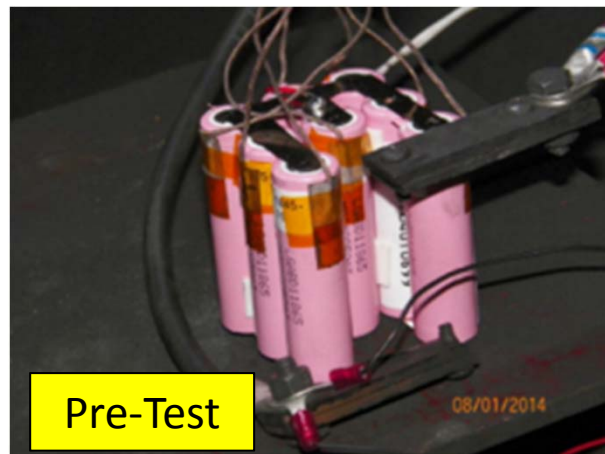
# 8P Bank Overcharge

(7.2 A Charge Current to 64 V limit); 6 hours max

Li-ion Pouch



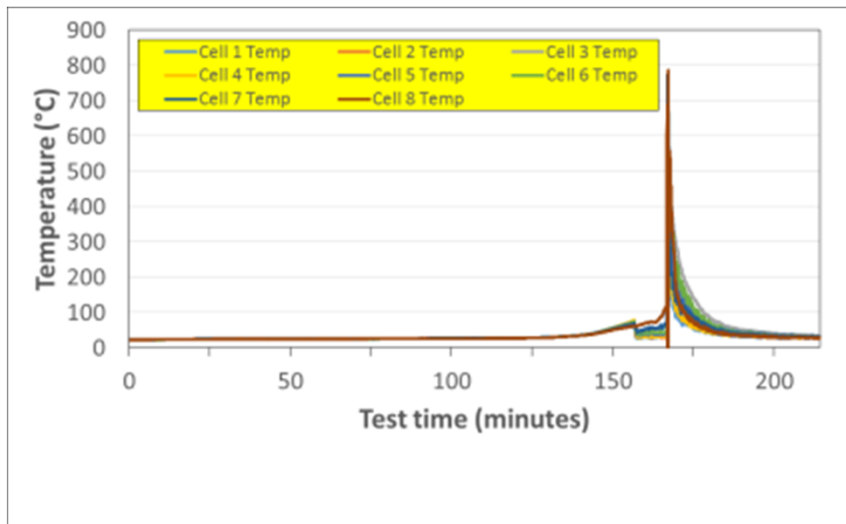
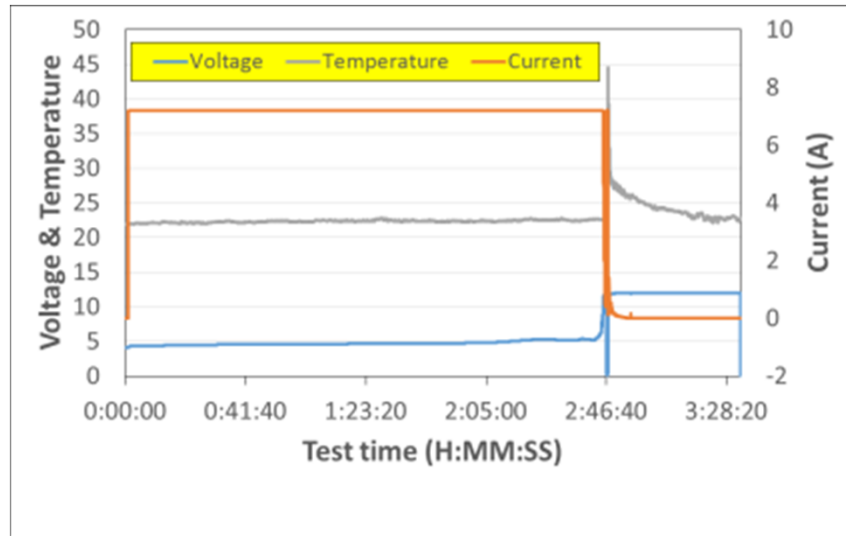
Li-ion 18650



# 8P Bank Overcharge

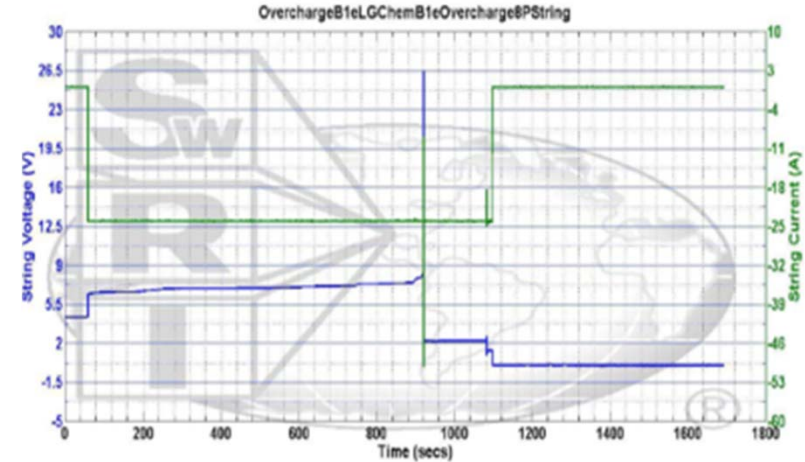
## Li-ion Pouch

(7.2 A Charge Current to 64 V limit); 6 hours max

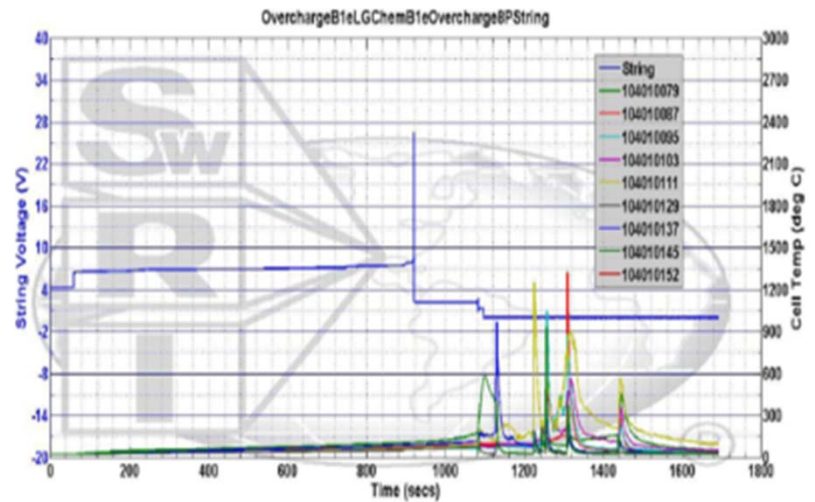


## Li-ion 18650

(24 A Charge Current to 64 V limit); 6 hours max



Overcharge Test B1.e String Voltage and String Current



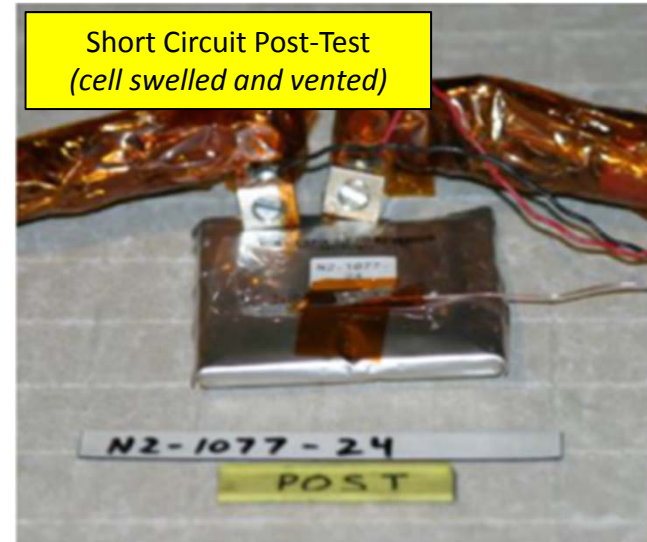
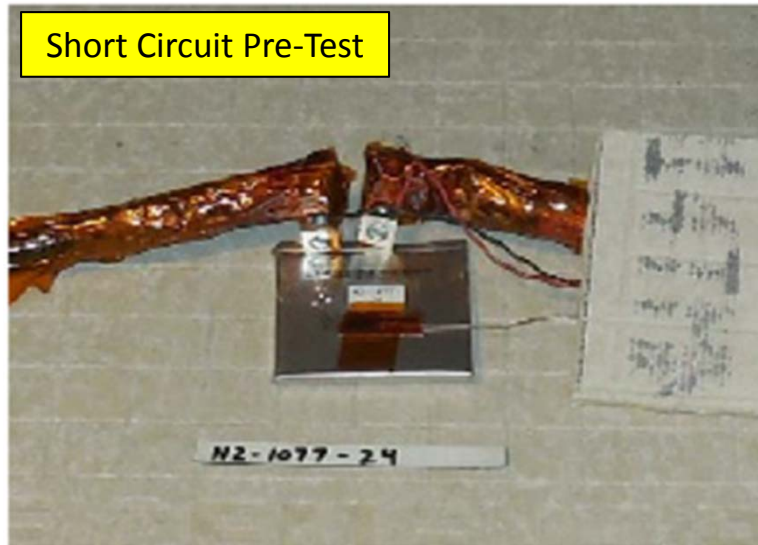
Overcharge Test B1.e String Voltage and Cell Temperatures



# Cell-Level External Short Circuit Test

Load  $\leq 10 \text{ m}\Omega$  for 2 hours

Li-ion Pouch



Li-ion 18650



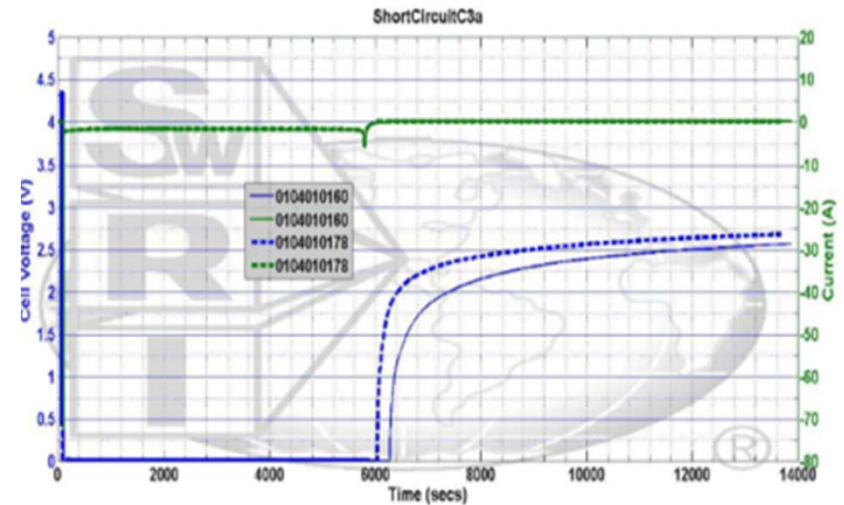
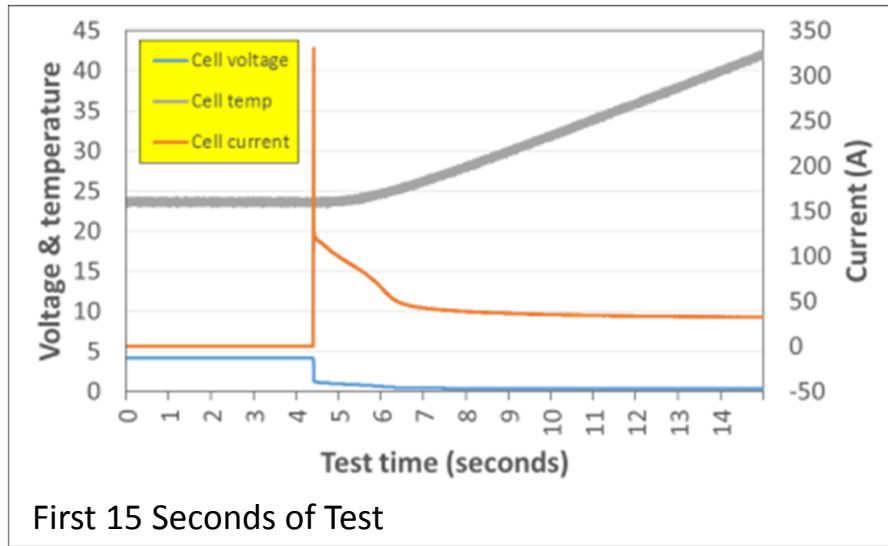


# Cell Level External Short Circuit Test

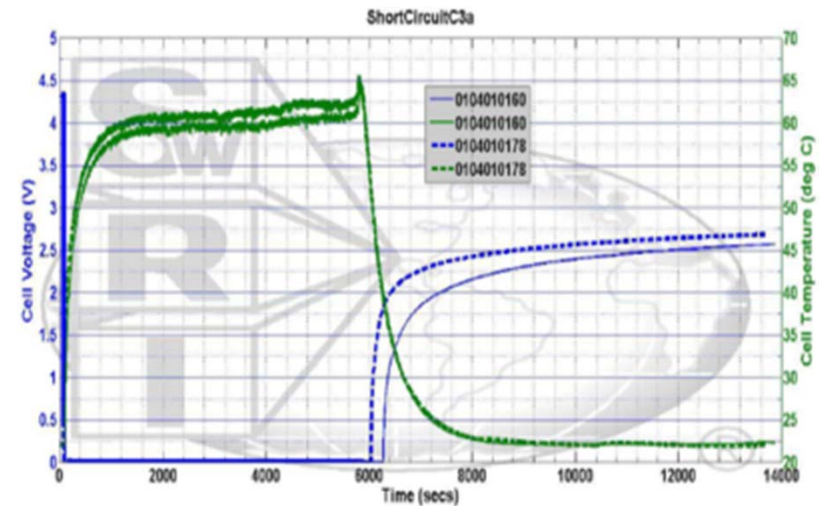
Li-ion Pouch

(Load  $\leq 10 \text{ m}\Omega$  for 2 hours)

Li-ion 18650



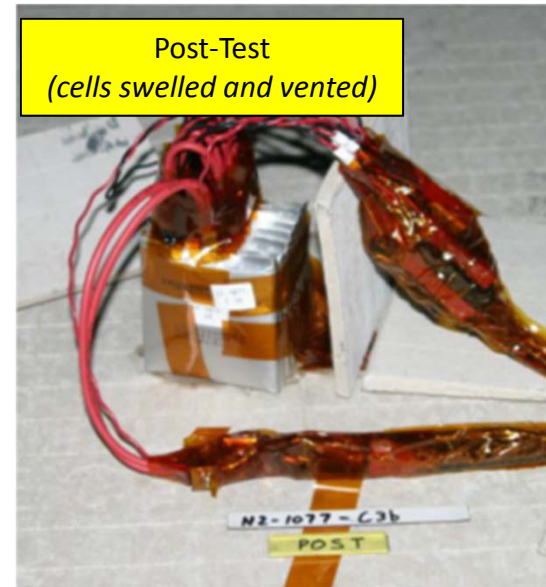
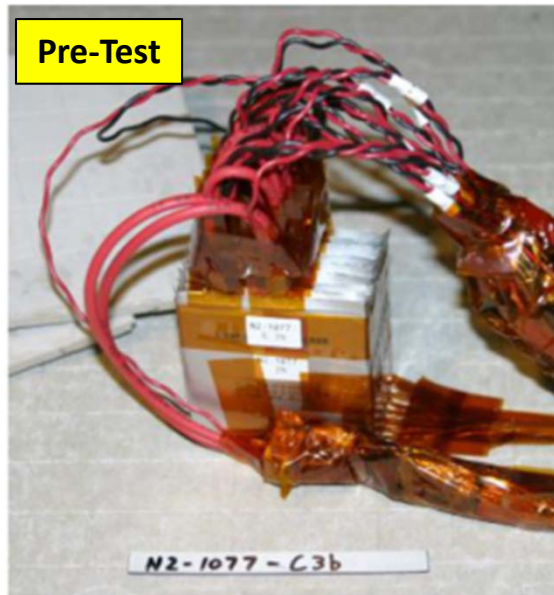
Short Circuit Test C3.a Voltage and Current



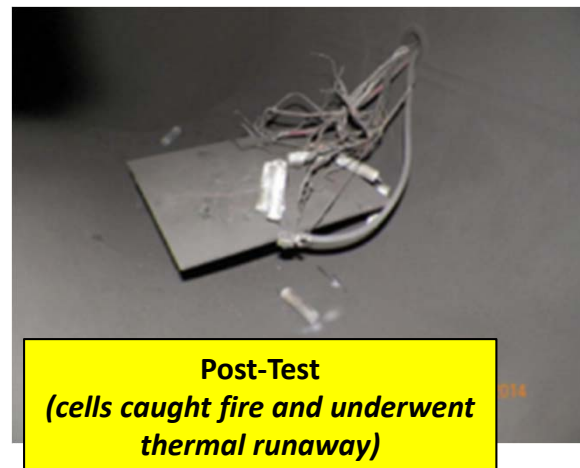
Short Circuit Test C3.a Voltage and Temperature

# 9S External Short Circuit Test at 100% SOC

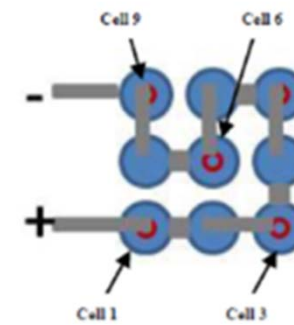
## Li-ion Pouch



## Li-ion 18650

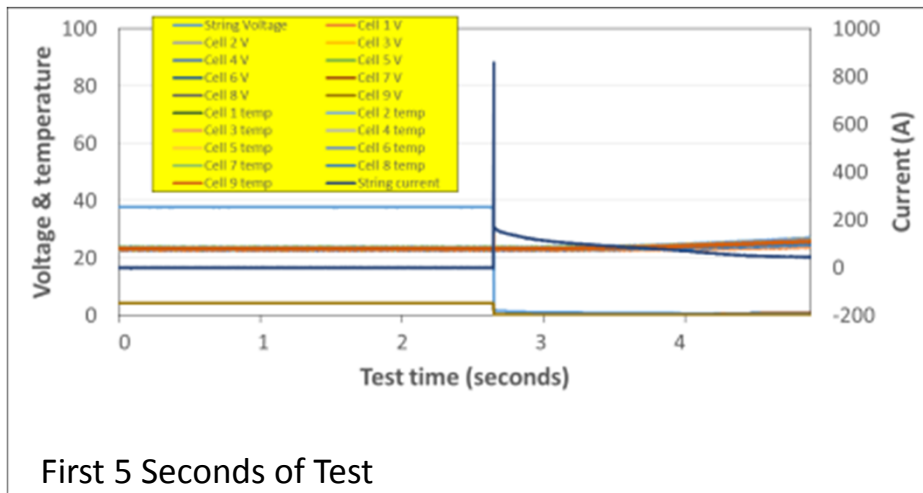


Cell Numbering for string is as follows.

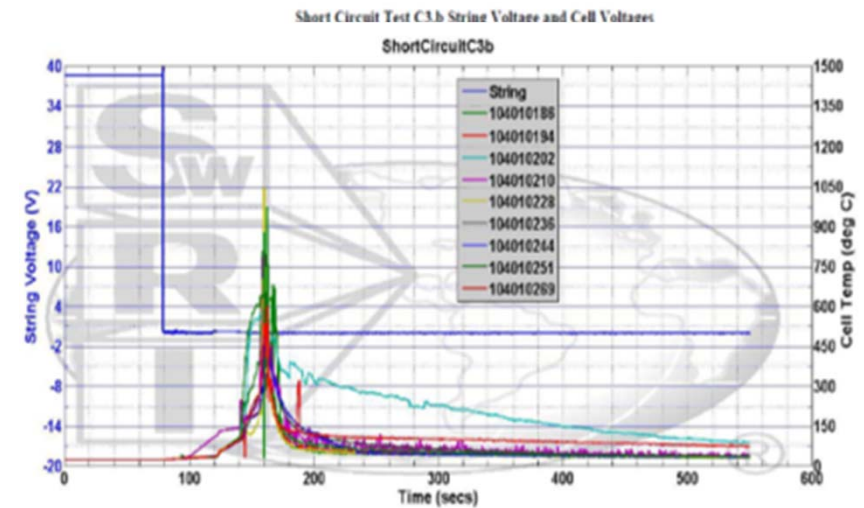
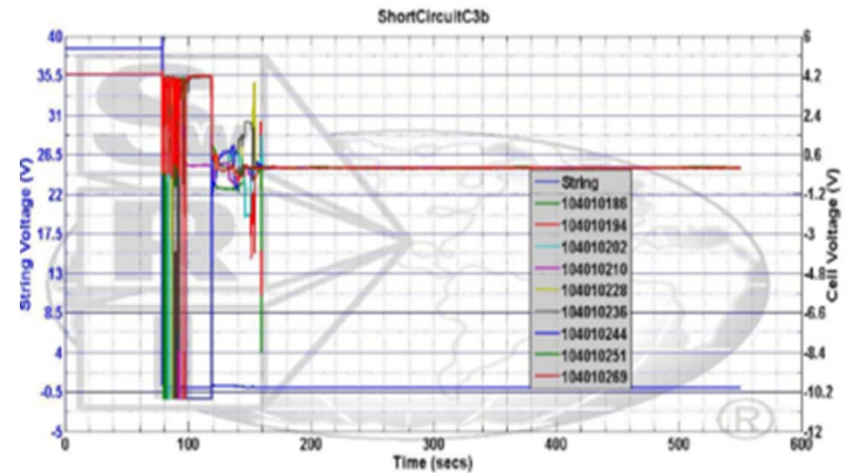


# 9S External Short Circuit Test at 100% SOC

## Li-ion Pouch



## Li-ion 18650



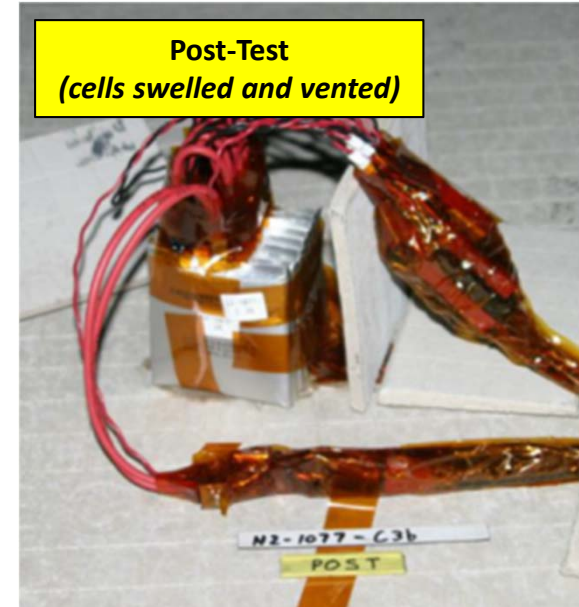
Short Circuit Test C3.b String Voltage and Cell Temperatures



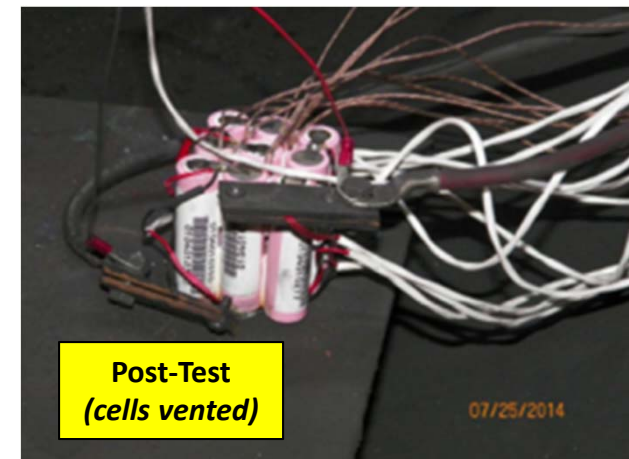
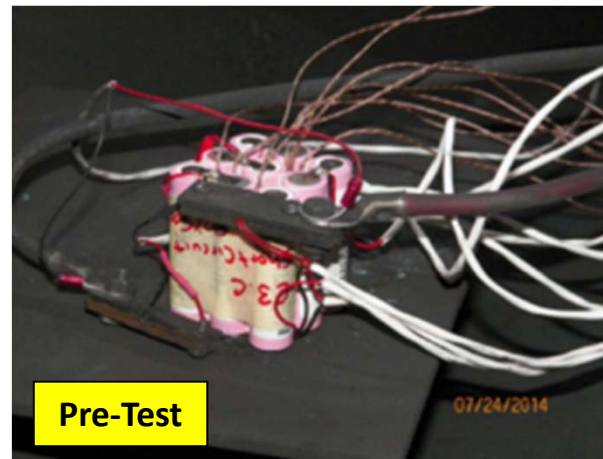
# 9S String External Short Circuit Test at 80% SOC

Both Modules were fully charged And then discharged by 20% (80% SOC or 20% DoD)

Li-ion Pouch



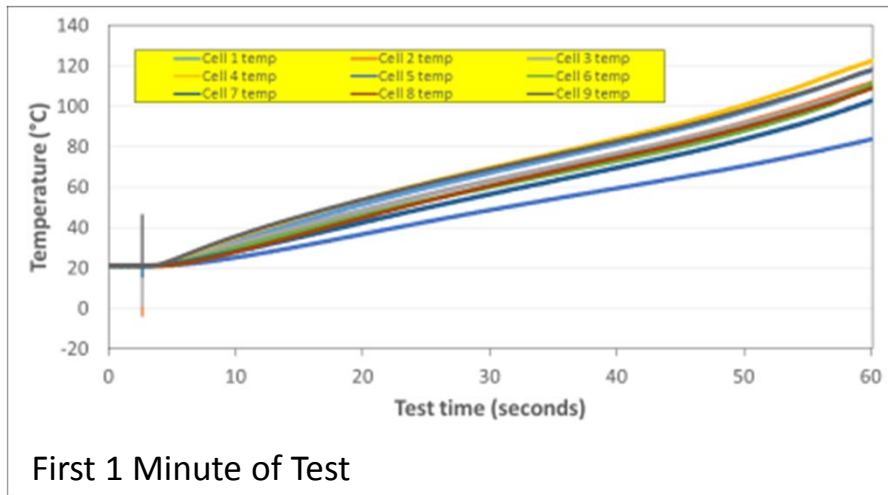
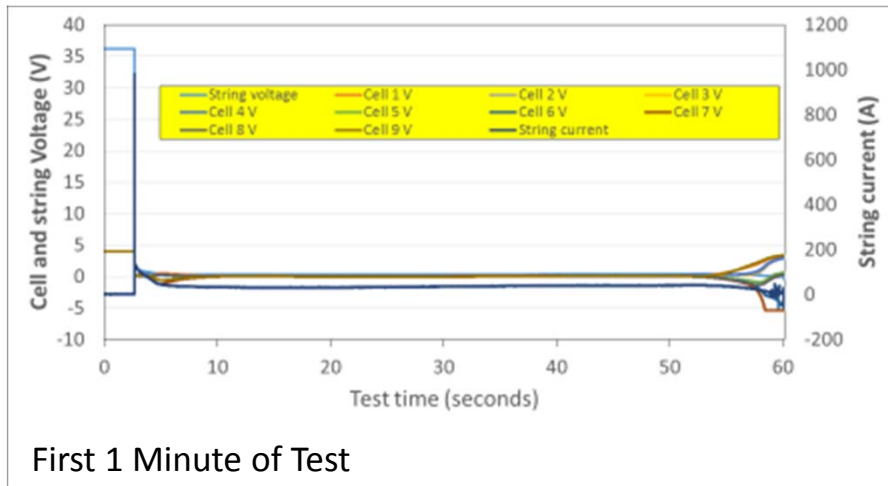
Li-ion 18650



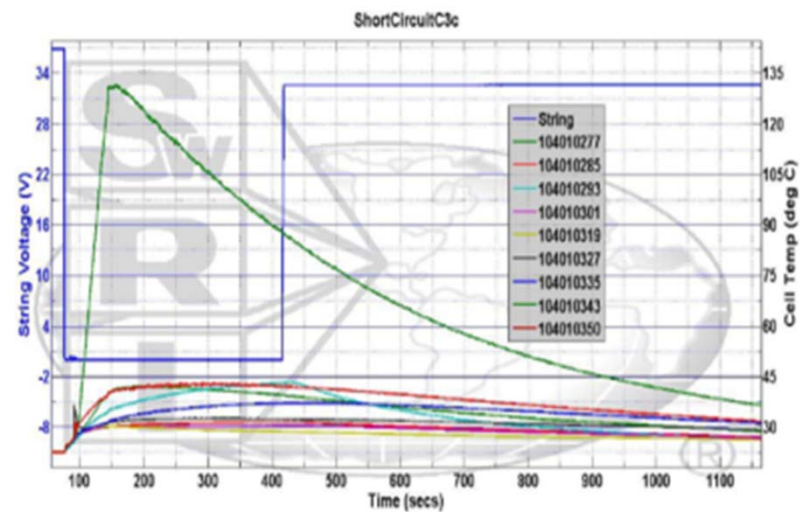
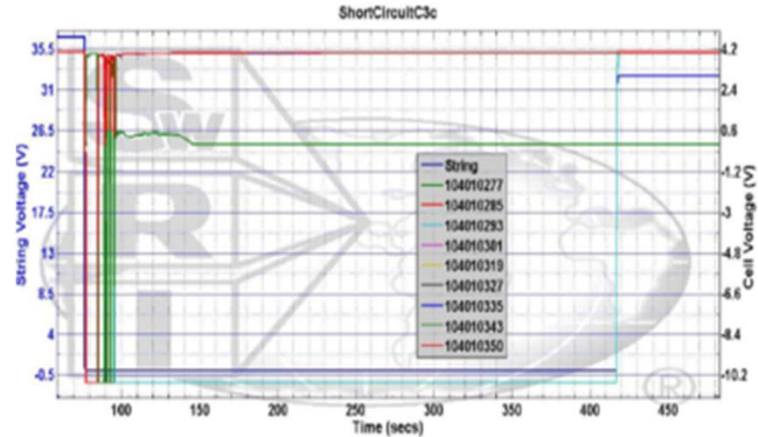


# 9S External Short Circuit Test at 80% SOC

## Li-ion Pouch



## Li-ion 18650

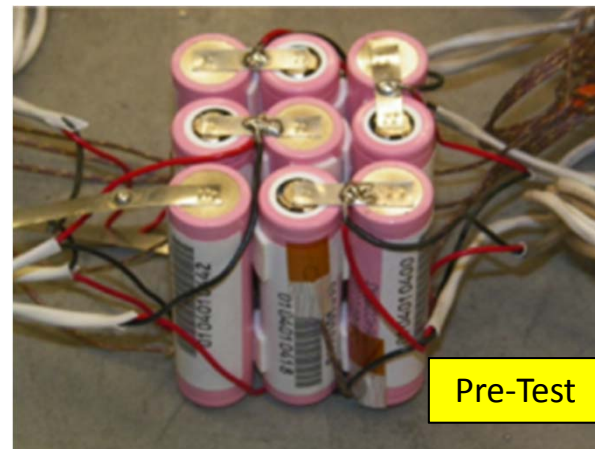


# 9S External Short Circuit Test at 70% SOC

Li-ion Pouch

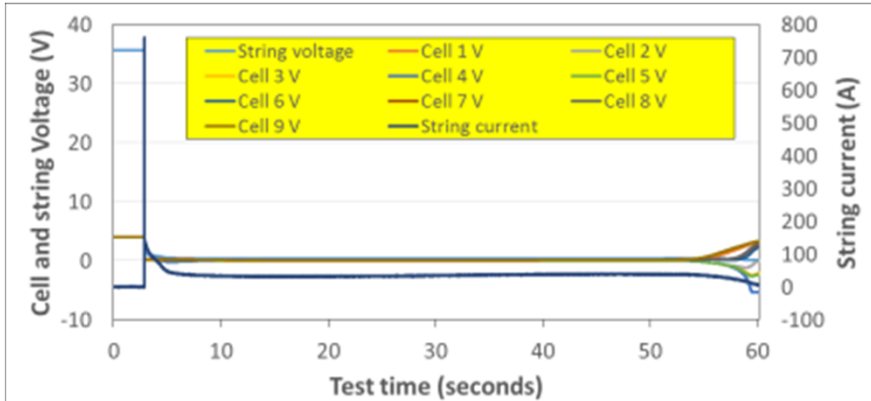


Li-ion 18650

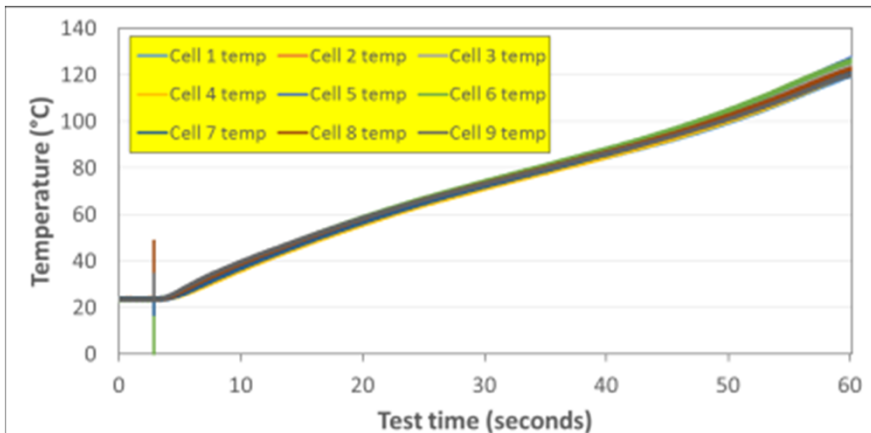


# 9S External Short Circuit Test at 70% SOC

## Li-ion Pouch

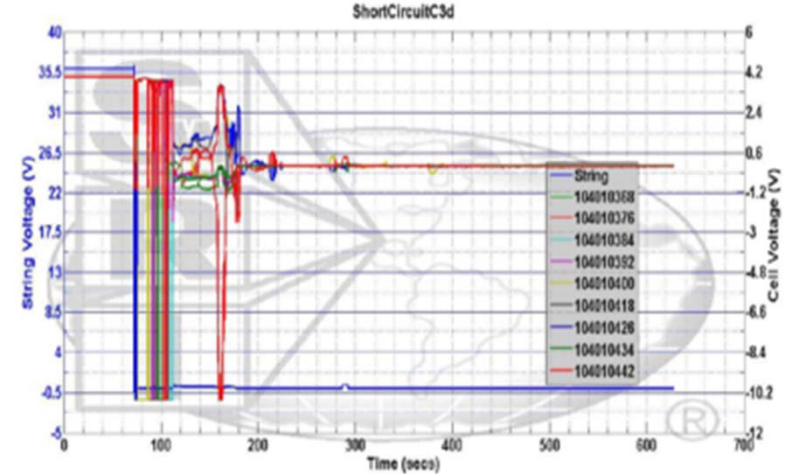


First 1 Minute of Test

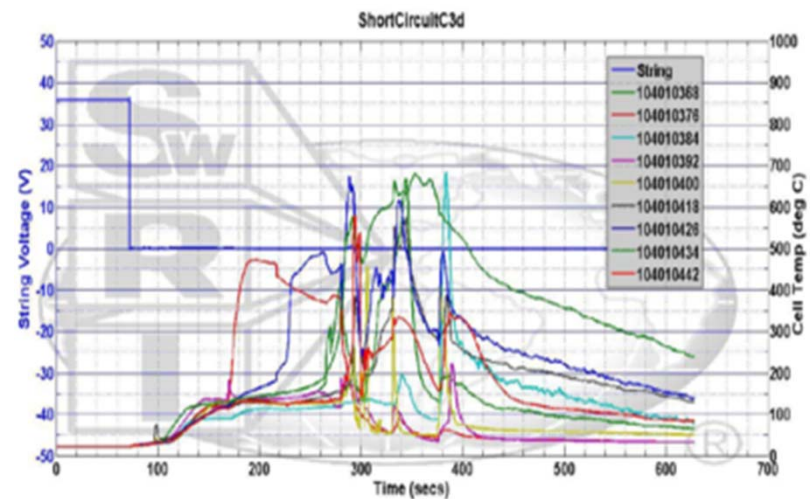


First 1 Minute of Test

## Li-ion 18650



Short Circuit Test C3.d String Voltage and Cell Voltage

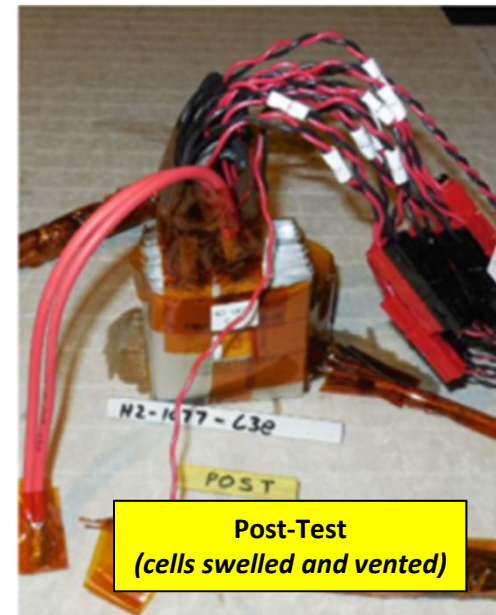


Short Circuit Test C3.d String Voltage and Cell Temperatures

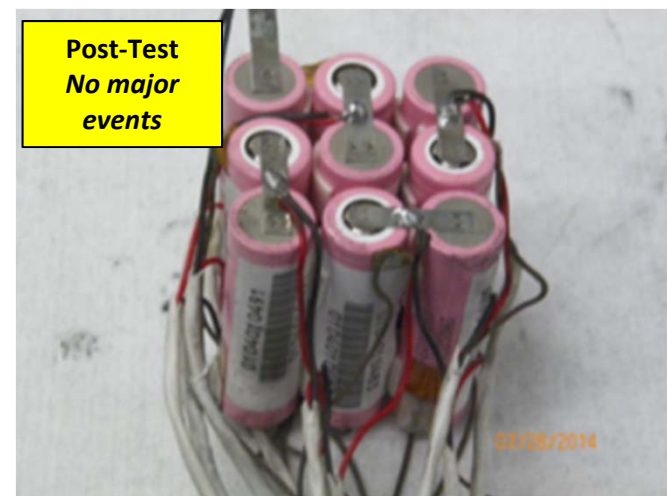


# 9S External Short Circuit Test at 50% SOC

Li-ion Pouch



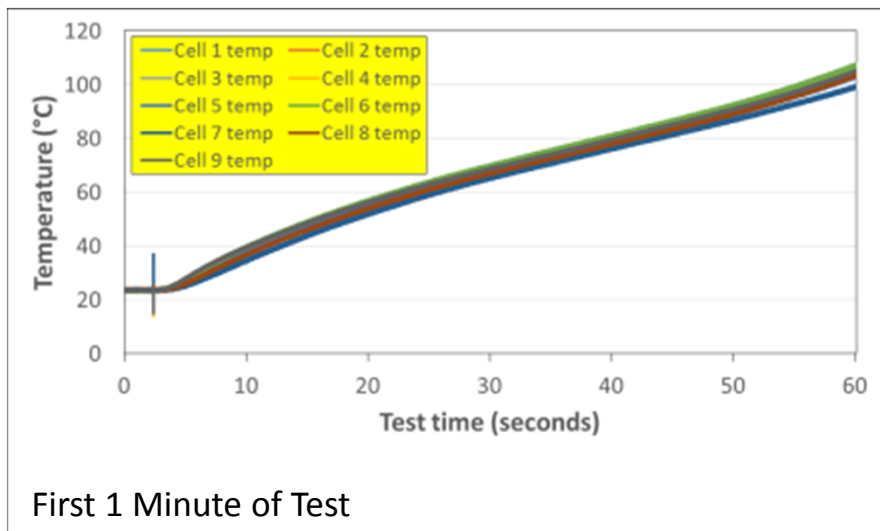
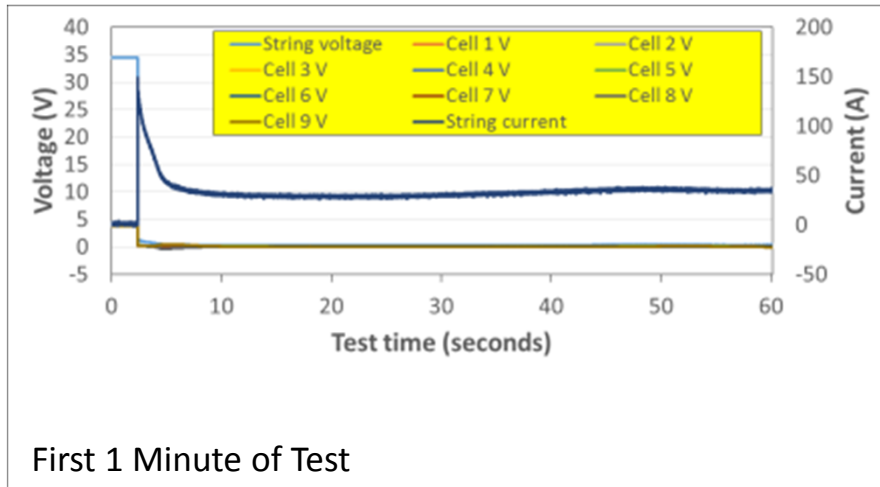
Li-ion 18650



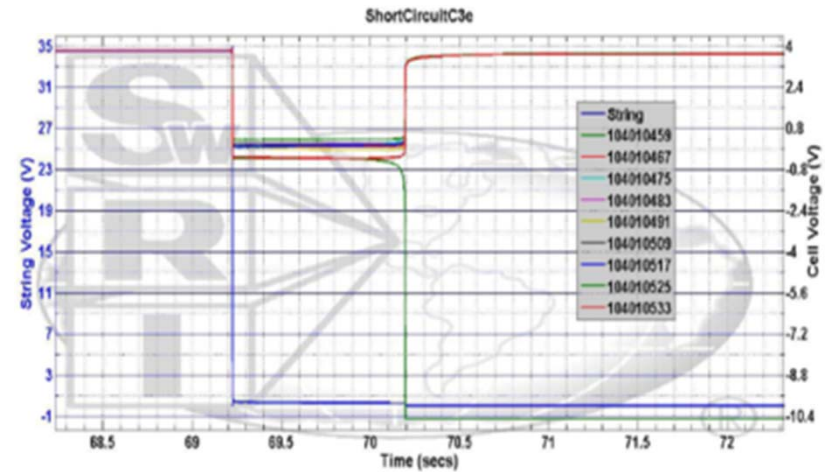


# 9S External Short Circuit Test at 50% SOC

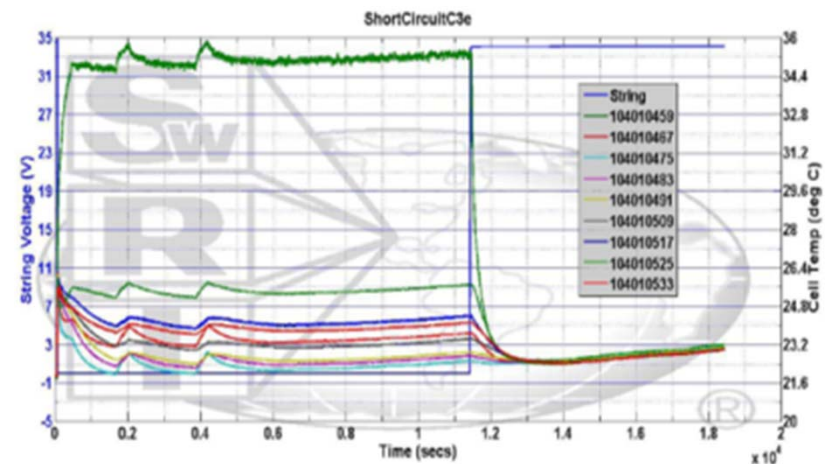
## Li-ion Pouch



## Li-ion 18650



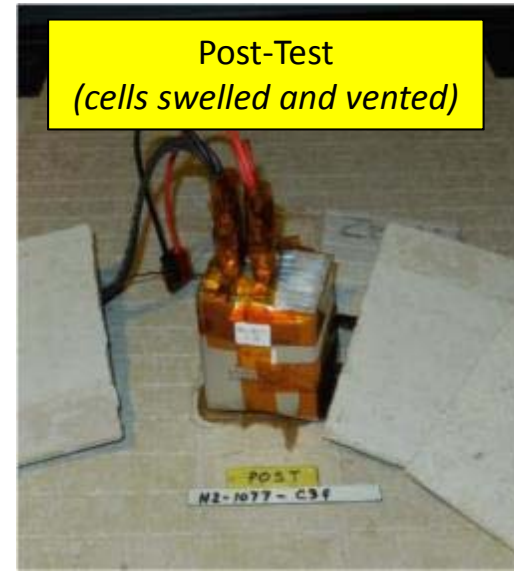
Short Circuit Test C3.e String Voltage and Cell Voltages - Zoomed



Short Circuit Test C3.e String Voltage and Cell Temperatures

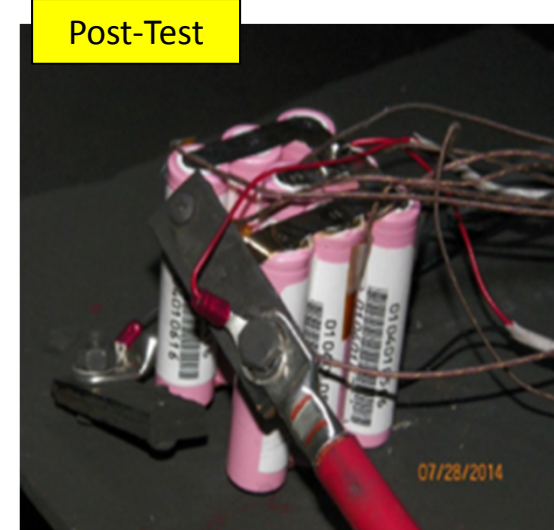
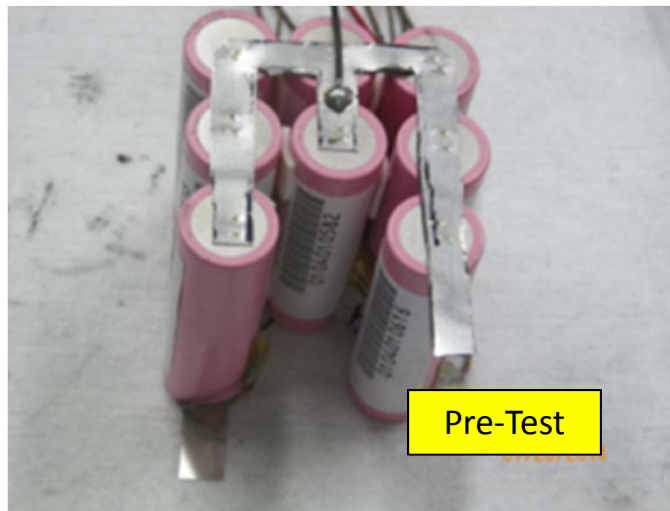
## 10P Bank External Short Circuit Test at 100% SOC

Li-ion Pouch



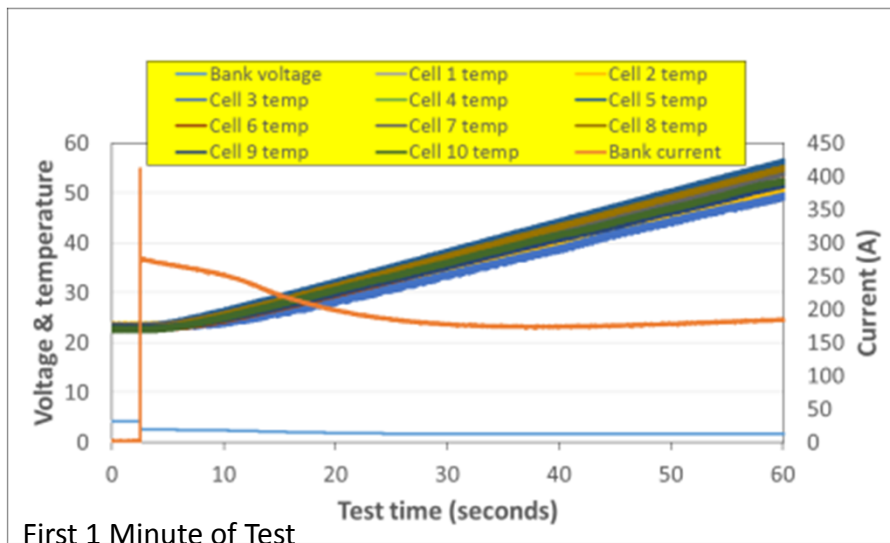
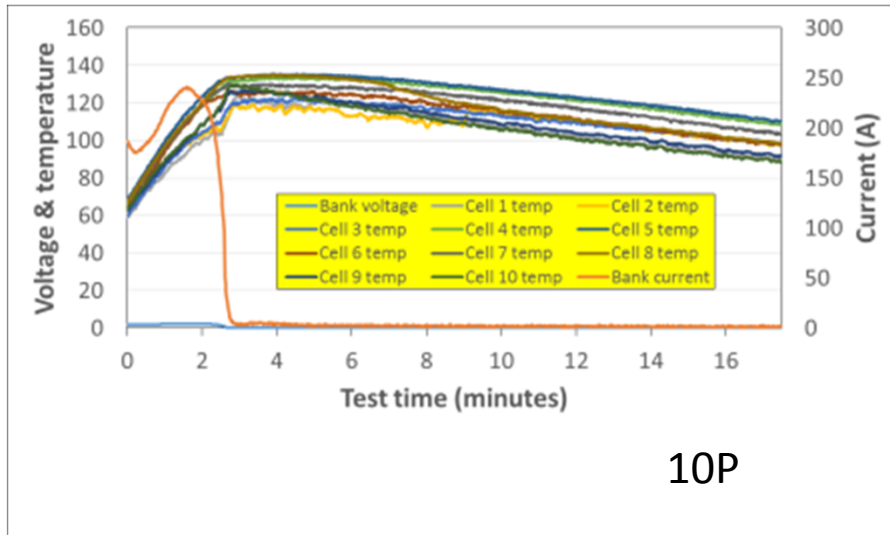
## 8P Bank External Short Circuit Test at 100% SOC

Li-ion 18650

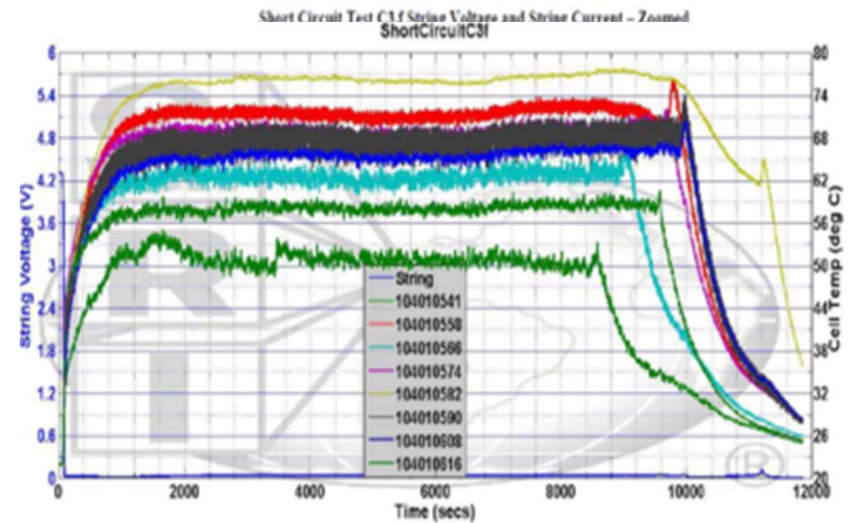
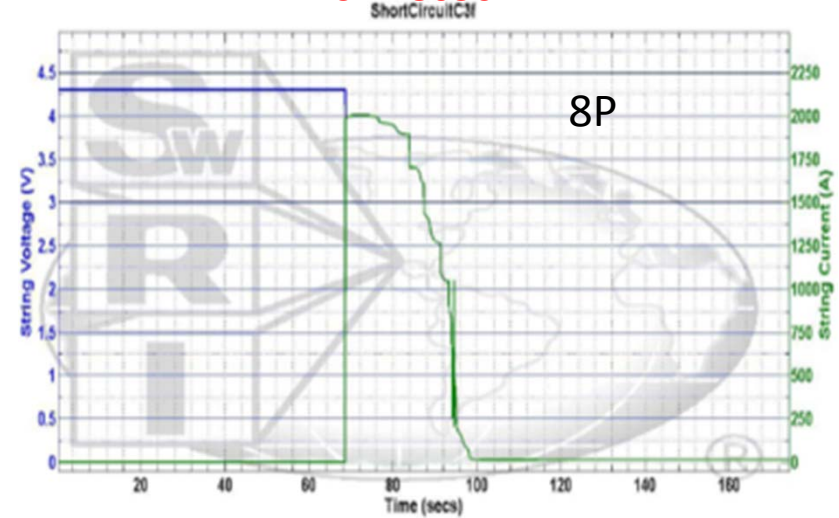


# Bank External Short Circuit Test at 100% SOC

Li-ion Pouch



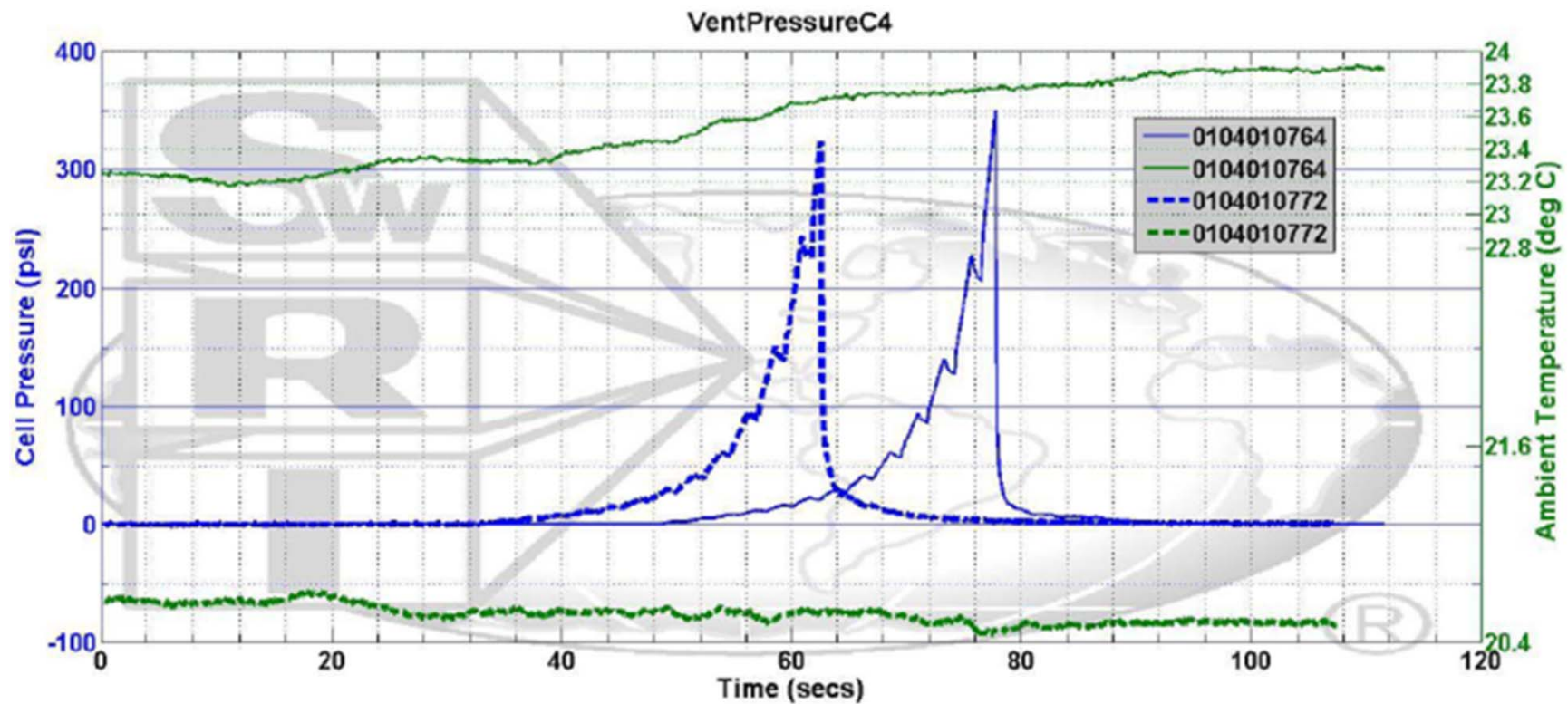
Li-ion 18650



Short Circuit Test C3.f String Voltage and Cell Temperatures



# Li-ion 18650 Cell Vent Pressure Test



Vent Pressure Test Pressure and Ambient Temperature



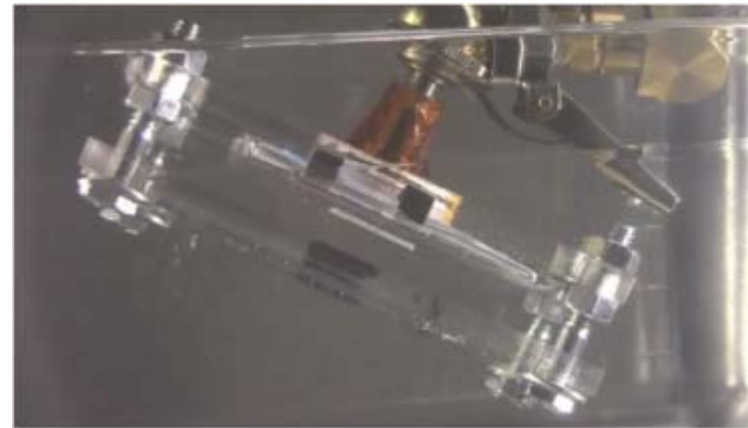
# Li-ion Pouch Cell Burst Pressure Test

## C.4 Burst pressure test (2 cells)

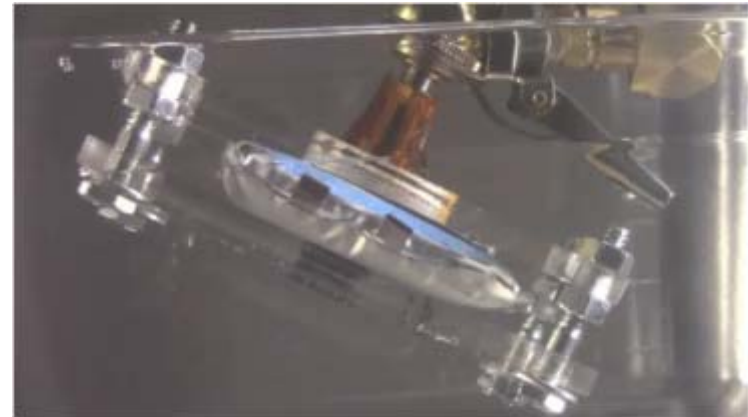
A small hole was pierced in the center of a fully discharged cell. A valve was affixed over the hole using a suitable adhesive. The cell was placed in a fixture and suspended in mineral oil. A tank of argon gas was connected to the valve. The pressure was slowly increased until the cell jacket burst, as evidenced by bubbles in the oil.



Cell Burst Pressure Test Set-Up



Cell Suspended in Oil in Beginning of Test

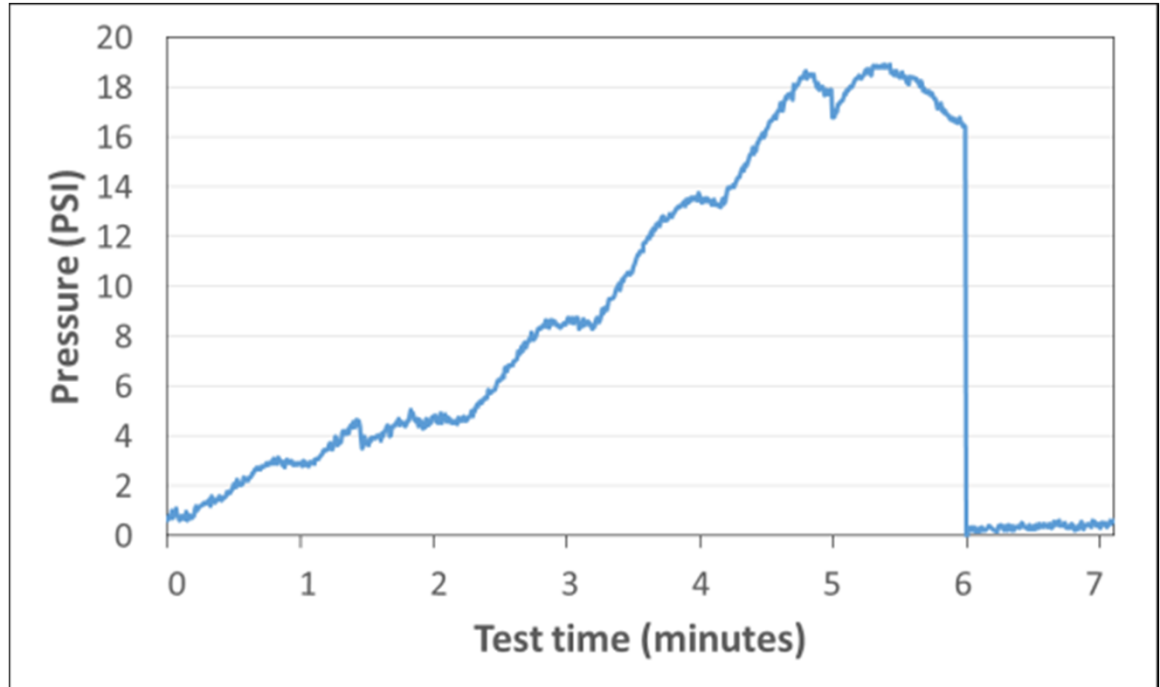


Cell Suspended in Oil Near End of Test  
(cell swelled)

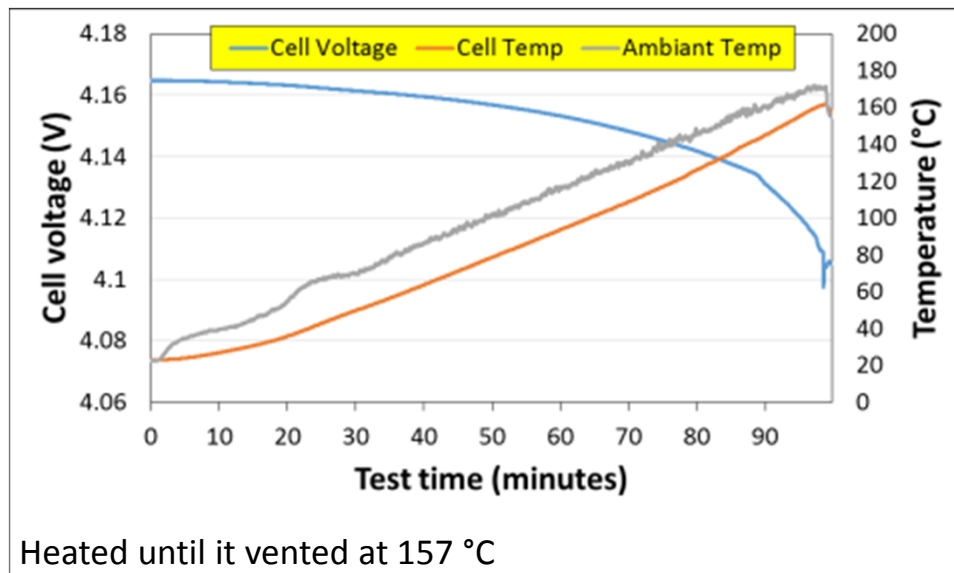
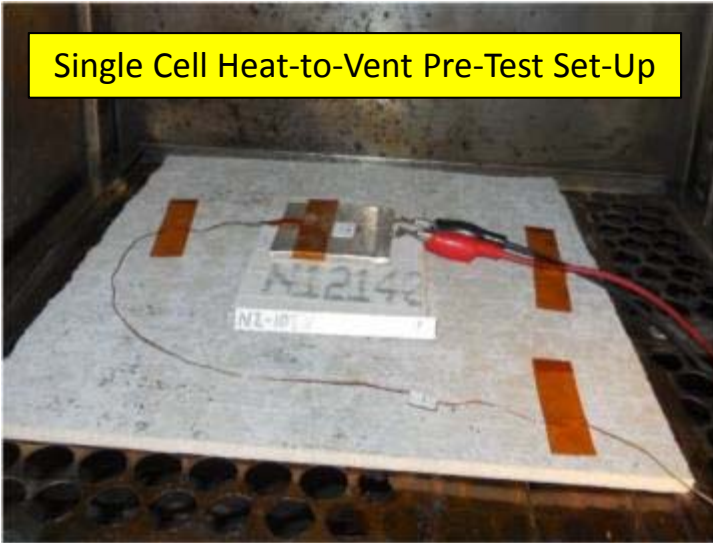
# Li-ion Pouch Cell Burst Pressure Test Results



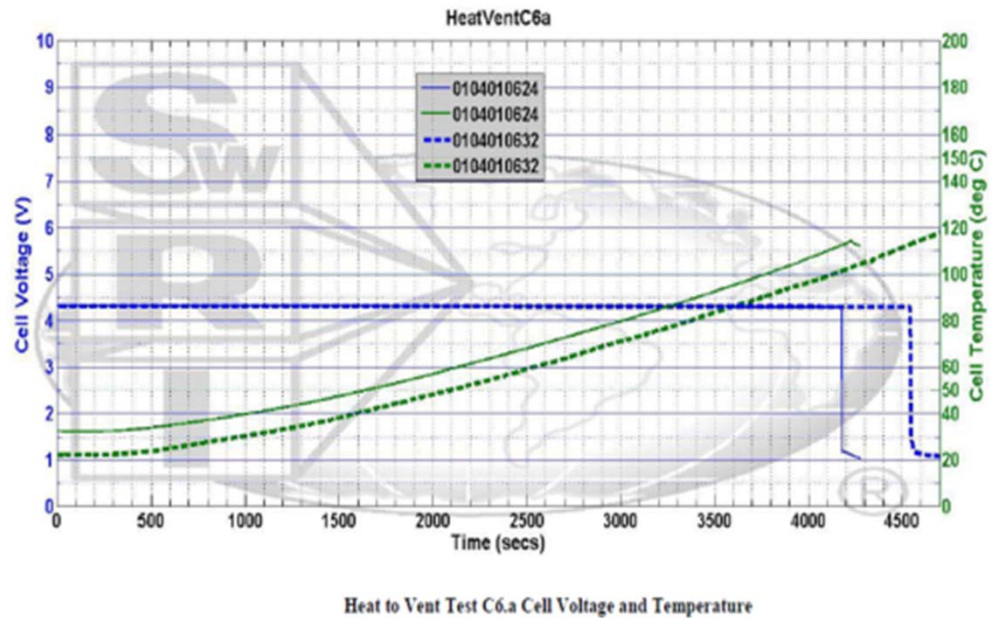
Cell burst at 18.55 psi. The cell burst along the edge opposite the tabs.  
(Note: This is a folded edge, not a sealed seam.)



# Li-ion Pouch Cell Heat-to-Vent Test at 100% SOC



# Li-ion 18650 Cell Heat-to-Vent Test at 100% SOC



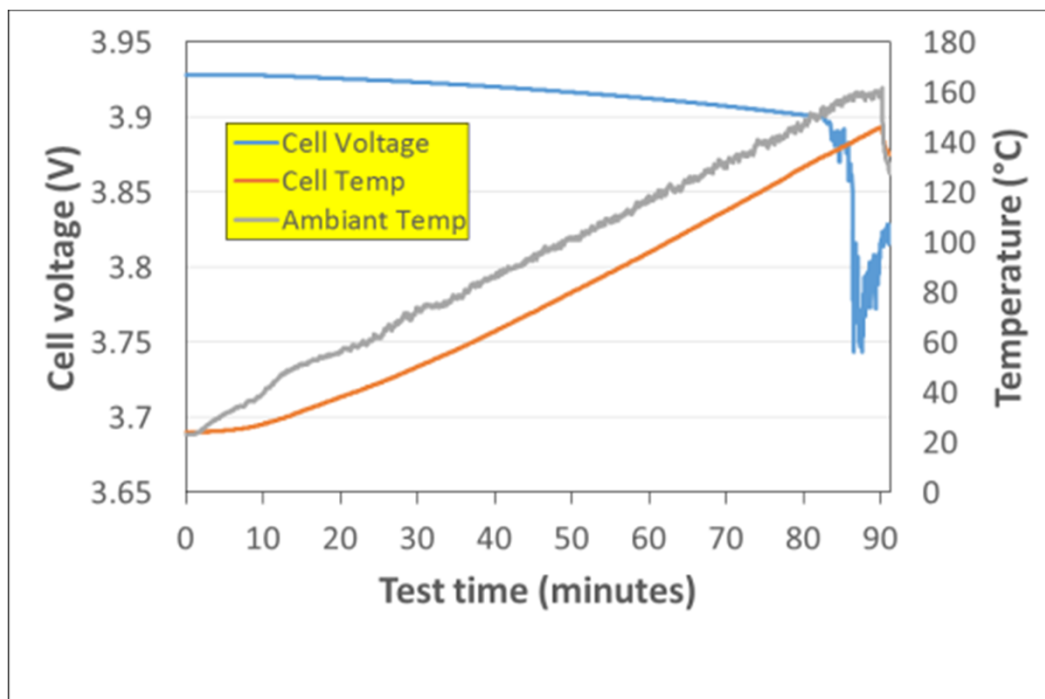
Heat damage observed at positive end



# Li-ion Pouch Cell Heat-to-Vent Test (70% SOC)



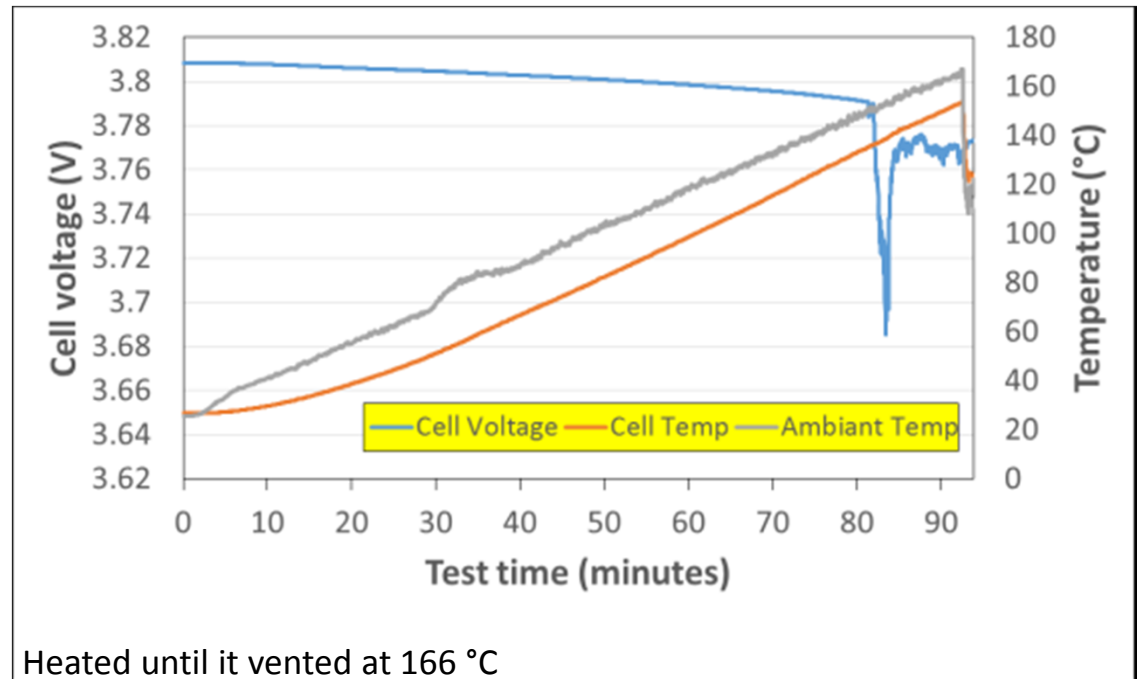
Cell 76 Heat-to-Vent Post-Test  
(cells swelled and vented)



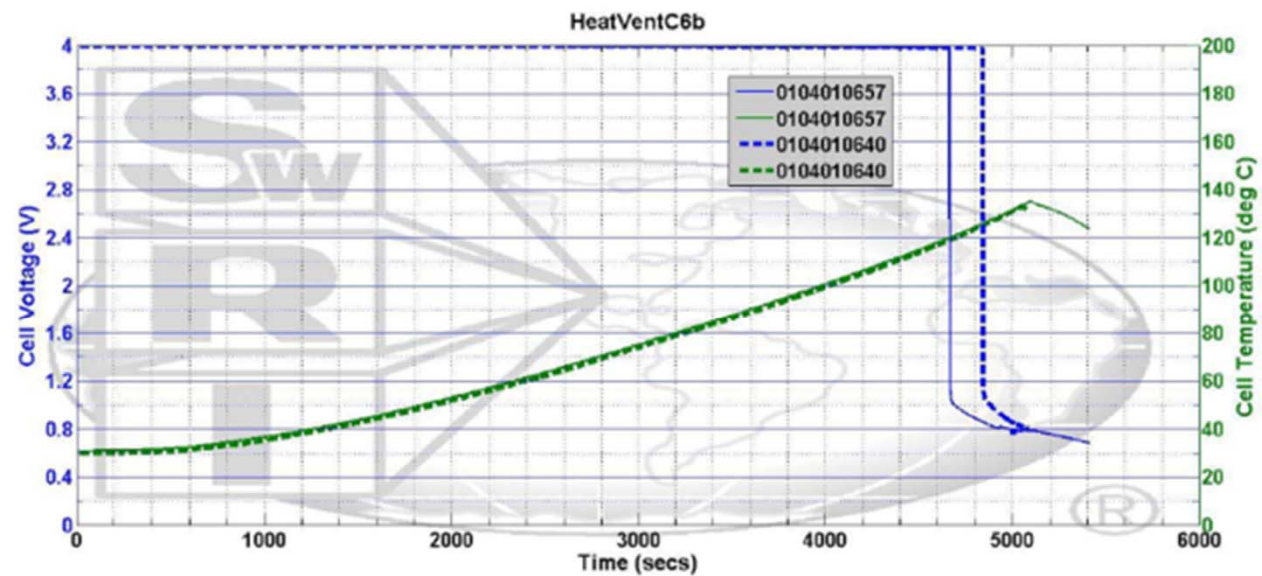
# Li-ion Pouch Cell Heat-to-Vent Test (50% SOC)



Cell 78 Heat-to-Vent Post-Test  
(cells swelled and vented)



# Li-ion 18650 Heat-to-Vent Test at 70% SOC

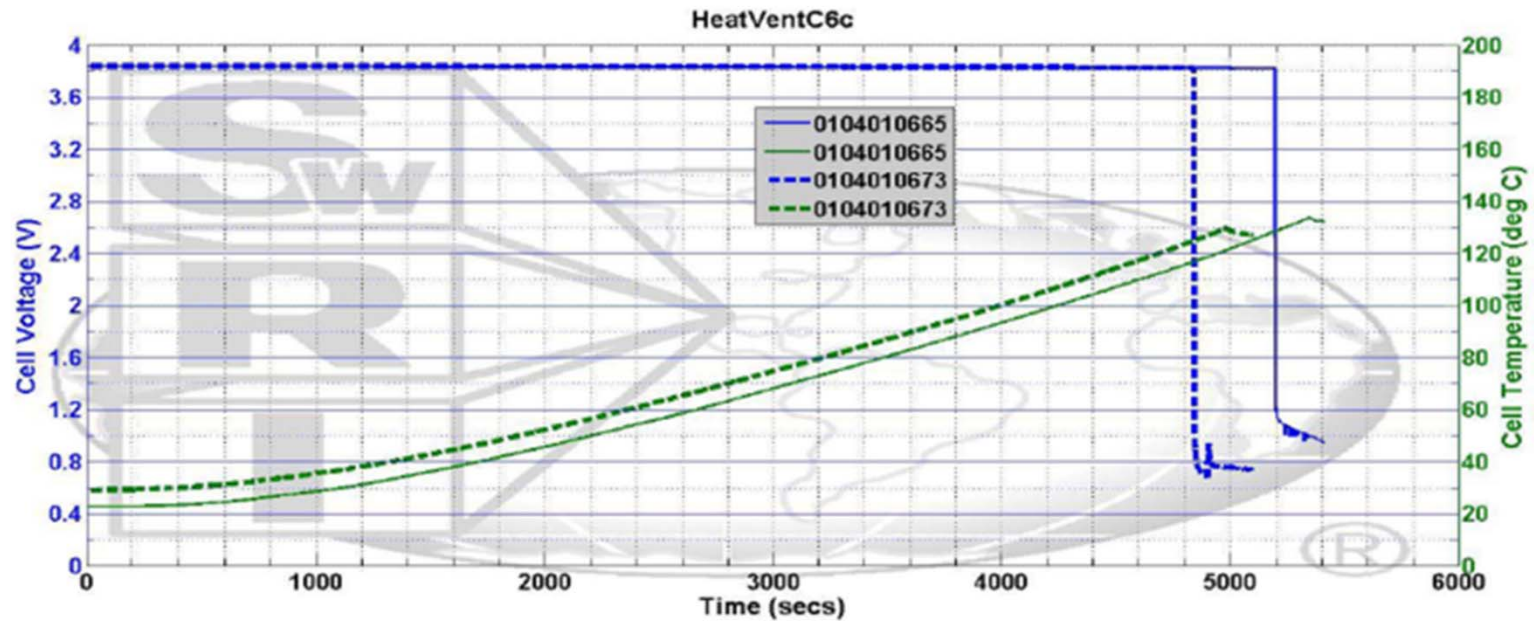


Heat to Vent Test C6.b Cell Voltage and Temperature



Swelling on positive end

# Li-Ion 18650 Heat to vent at 50% SOC



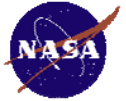
Heat to Vent Test C6.c Cell Voltage and Temperature



No apparent damage

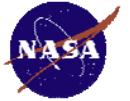


# Summary



- The LG 18650 li-ion cells have a tolerance to off-nominal conditions at the single cell level.
- The LG polymer/pouch li-ion cells do not have the same tolerance to off-nominal conditions at the single cell level. The cells go into thermal runaway at 1C and 0.5 C rates of overcharge current.
- Neither cell designs show a tolerance to overcharge at the bank level.
- The LG pouch cells do not show tolerance to an external short at the cell or string and bank level at various SOC. They swell and exhibit venting but do not go into thermal runaway.
- The LG 18650 li-ion cells in strings display venting or thermal runaway when subjected to external short tests at different SOC except the 50% SOC where very low temperatures were observed.
- The LG 18650 cells in a 8P bank configuration when subjected to an external short displayed no venting at full SOC with temperatures below 100 °C through the entire test.
- The LG pouch cells under the heat to vent tests at different SOC, did not exhibit any thermal runaway but showed cell swelling under all SOC with venting occurring at almost the same temperatures irrespective of SOC.
- The LG 18650 cells, under the heat to vent tests at different SOC, displayed venting at higher temperatures when the SOC was decreased. No thermal runaway was observed at any SOC although cell damage was observed at 100% SOC, cell swelling was observed at 70% SOC and no apparent damage was observed at 50% SOC.





# Acknowledgments

- Southwest Research Institute
- Mobile Power Solutions

